APPLE POLLINATION STUDIES

IN THE

ANNAPOLIS VALLEY, N.S.

CANADA

1928-1932

469

32555

32555

UNDER THE DIRECTION OF

W. H. BRITTAIN

DOMINION OF CANADA
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ERRATA

Page 5, line 23, for "*anthers discharge their pollen shortly before the stigmas are receptive*" read *the stigmas become receptive shortly before the anthers dehisce.*

Page 8, line 19, for "*apple*" read *pollen*, and in line 26, for "*later*" read *earlier* and for "*earlier*" read *later*.

Page 12, line 23, for "*C. A. Atwood*" read *C. E. Atwood.*

Page 13, line 8, for "*south*" read *north.*

Page 14, fig. 2, for "*1 mile=1 inch*" read *·26″=1 mile.*

Page 19, line 39, for "*1932*" read *1931.*

Page 29, line 22, for "*in the case*" read *is the case.*

Page 44, line 16, for "*aberation*" read *aberration.*

Page 46, fig. 11, for top percentage figure "*85*" read *90.*

Page 48, line 3, for "*varied*" read *varies.*

Page 50, line 5 and 6, for "*as in the case of the*" read *due to certain.*

Page 86, line 21, for "*each year,*" read *each alternate year.*

Page 102, fig. 40, for "*Scale 4″=1 mile*" read *scale ·66″=1 mile.*

Page 104, fig. 42, for "*4″=1 mile*" read *·55″=1 mile.*

Page 104, fig. 43, for "*Scale 4″=1 mile*" read *scale ·55″=1 mile.*

Page 108, line 6, for "*over winter*" read *overwinter* and in line 33, for "*1928-31*" read *1928-1930.*

Page 116, line 1, for "*5300A*" read *5300Å* and in line 3, "*5530A*" read *5530Å*.

Page 120, line 4, for "*falls*" read *falling.*

Page 129, line 1, for "*22.*" *read 22,.*

Page 144, line 47, for "*result*" read *results.*

Page 153, line 20, for "*1.23*" read *1.94,* and in line 49, for "*1.27*" read *1.94.*

Page 155, line 26, omit comma after "may."

Page 159, line 30, for "*the bees were found to be*", read *it was found that the bees were.*

Page 160, line 18, for "*data*" read date.

Page 167, line 4, for "*e.g.*" read *i.e.*

Page 168, line 6, for "*spray dust*" read *spray and dust* and in line 33, for "*arsenical and*" read *arsenicals and.*

Page 173, heading table No. 34, for "*1920*" read *1929.*

Page 175, last line, for "*1928-1931*" read *1928* and *1929.*

Page 176, line 29, for "*orchard*" read *orchard being available.*

Page 188, line 39, for "*.0008*" read *.00008.*

Page 190, under Darlington, C. D., and Moffatt, A. A., delete 1926 citation.

APPLE POLLINATION STUDIES IN THE ANNAPOLIS VALLEY

BY W. H. BRITTAIN

POPULAR SUMMARY

GENERAL

The investigations described in the following pages grew out of a request of the Department of Agriculture of Nova Scotia and of various horticultural organizations, that a study be undertaken to determine whether the alleged destruction of pollinating insects by poison dusts and sprays was adversely affecting the set of fruit in commercial apple orchards.

As a result of the initial survey, the work quickly broadened out into a study of the entire pollination problem. As indicated in the evidence presented, it was found that the hive bees of the Annapolis valley had indeed suffered great losses as a result of prevailing spraying and dusting practices. However, it was found that wild solitary bees were sufficiently abundant in most orchards during the period of the investigation, alone to effect pollination under favourable conditions. The results secured emphasized that the proper interplanting of cross-fruitful varieties was a crucial factor in the production of commercial crops.

THE PROCESS OF POLLINATION AND FERTILIZATION IN APPLES

The apple blossom is provided with five sepals, which persist at the "blossom end" of the apple, five petals, which are soon shed, twenty to twenty-five stamens, each with an anther containing pollen surmounting the filament and surrounding the five stigmas, which unite in a common style that leads to the ovary, these parts constituting the pistil of the flower. The stamens and pistil are the essential organs of the flower representing, respectively, the male and female parts.

The ovary is divided into five compartments each containing two egg cells, or four in the case of Northern Spy. As the anthers discharge their pollen shortly before the stigmas are receptive, this renders it difficult for pollen from a flower to reach the stigmas of the same flower. There may be, however, a considerable number of blossoms on the tree that receive pollen from their own or neighbouring flowers.

The mere transfer of the pollen from anther to stigma constitutes *pollination* and is usually effected by the aid of insects. The transfer of pollen from the anther of one flower to the stigma of another *of the same variety* is known as *self-pollination.* The transfer to the stigma of the flower *of another variety* is *cross-pollination.* Following pollination with the pollen of a suitable variety, the pollen tube develops, grows down the style through the tissue and finally reaches the ovary, where, upon penetration, the sperm is discharged into the embryo sac, where it unites with the egg cell, thus accomplishing *fertilization,* this process usually resulting in the formation of seed. This initiates the growth and development of the fruit and is requisite to setting. Where the ovules fail of fertilization, or where, for any reason development is checked the blossoms are soon shed.

It is not, of course, necessary for the entire complement of seeds to be produced in order for normal apples to develop, but the larger the number of seeds

that do develop in a fruit the better chance is there for that fruit to succeed in the competition for nutrients and to remain on the tree until the harvest. Apples with one or more compartments devoid of seed are likely to be one sided or otherwise abnormal. While it is true that a certain amount of fruit may develop without seed in some varieties, especially in Gravenstein, this has little commercial significance as the percentage so produced is small.

From the standpoint of their requirements for pollination apples may be either (1) *self-fruitful* or (2) *self-unfruitful*, *i.e.*, they are capable of producing mature fruit when pollinated with their own pollen or (2) they require the pollen from another variety in order to produce fruit. We shall see later that few, if any, varieties are completely self-unfruitful, and hence the expression "partially self-fruitful" largely loses its meaning. In fact, self-fruitfulness varies from varieties that yield little or no fruit when self-pollinated to others that produce a set little short of that obtained from favourable cross-pollinations.

When the pollen from one variety results in fruit production when placed on the stigma of another variety, the first variety is said to be *cross-fruitful* with the second variety. Just as few apple varieties are completely self-unfruitful, so there are few cases in which the pollen from one variety is completely useless for another variety, though there are many combinations that give very poor results commercially. Therefore, the expressions "commercially self- or cross-fruitful" would be more accurate.

THE PROBLEM OF POLLINATION

In order for apple orchards to be pollinated there must be present in the orchard (1) a suitable pollen supply in the form of varieties capable of producing fruit when the pollen is carried to the stigmas of other varieties present and (2) an adequate supply of insect pollinators in the form of either hive or wild bees, to ensure that cross-pollination occurs. This is because all varieties of apples produce better crops when cross-pollinated by another suitable variety and some of them ordinarily set very little when self-pollinated. The admixture of varieties is important, because some varieties yield pollen which, when applied to the stigmas of certain others, results in low yields, sometimes even less than when the same variety is self-pollinated. All varieties require the work of insect pollinators, even the most self-fruitful, since wind is a negligible factor in the pollination of the apple.

The problem of apple pollination is rendered much less acute than it might otherwise be by the fact that only a small amount of pollination is necessary. If one out of twenty of the original blossoms develops into fruit a commercial crop will result, provided there is a good bloom, whereas, in the cherry, for example, a much larger set is required. Again, self- and cross-unfruitfulness are much less pronounced in the apple than in the cherry. It may also be noted that since the cherry has but a single seed, if that seed fails to be fertilized the fruit drops. Whereas, in the apple with its complement of ten or twenty seeds, the fertilization of but a small proportion is necessary for setting and even seedless apples may be produced by some varieties.

In one variety studied, viz., the Baldwin, selfing may result in a commercial crop, though not as high a yield as is produced from the most fruitful crosses. In view of these facts, it is only to be expected that less difficulty would be experienced in ensuring cross-pollination of apple varieties than would occur in the cherry, where pronounced self-unfruitfulness and cross-unfruitfulness may occur. On the other hand, cases of over-pollination, resulting in biennial bearing, appear to occur in some varieties. Nevertheless it should be emphasized that, with the possible exception of Baldwin all varieties must be regarded as commercially self-unfruitful and that all, including Baldwin, benefit from cross-pollination. A definite problem results when (1) large blocks of highly self-unfruitful varieties

are planted together or (2) when cross-unfruitful varieties are mixed or (3) when *insect pollinators are insufficient in number.* The question of the inter-fruitfulness of varieties should be given consideration in connection with all grafting-out operations and also when new plantings of commercially desirable sorts are to be made.

To elaborate further upon this point it may be said that with respect to the two fundamentals for successful pollination, viz., (1) pollen supply and (2) insect pollinators, the following conditions may exist in commercial orchards:

1. There may be a suitable intermixture of inter-fruitful varieties and an *adequate population of insect pollinators.*

2. Cross-unfruitful varieties may be inter-planted, though insect pollinators are sufficiently abundant.

3. Varieties may be planted together in too large blocks to permit of effective cross-pollination, even though an abundance of insect pollinators may be *present.*

4. A similar condition to number 3, but without a sufficient number of insect pollinators.

5. Similar to number 1, but with an inadequate number of insect pollinators.

To simulate under experimental control, the foregoing conditions, trees of the Gravenstein, King, Baldwin, and Spy varieties were covered with tents and the following treatments given:—

1. Supplied with "bouquets," *i.e.*, blossoming limbs of the desired variety *placed in tubs of water, of an effective pollinizer and a hive of bees.*
2. Supplied with "bouquets" of an ineffective pollinizer and a hive of bees.
3. Not supplied with "bouquets" of any kind but with a hive of bees.
4. Not supplied with "bouquets" of any kind nor with a hive of bees.
5. Supplied with "bouquets" of an effective pollinizer but no bees.
6. Un-tented trees left to open pollination for comparison.

TABLE No. 1.—RESULTS OF TENT EXPERIMENTS, 1929-1932

Variety	Effective pollinizer and bees	Ineffective pollinizer and bees	No pollinizer and bees (selfed)	No pollinizer and no bees	Effective pollinizer but no bees	Open polli-nation
Gravenstein	10·90	1·14	2·12	0·67	0·47	9·91
King	5·42	3·58	3·32	1·03	1·81	4·74
Baldwin	8·17	4·96	7·77	3·49	5·05*	10·40
Spy	10·05	2·70	2·00	0·85	1·20	8·83

*Abnormally high per cent set in 1932 due to small number of blossoms on tree, has raised the general average for this treatment.

The results indicated in the accompanying table summarizing four years work, justify the following conclusions:—

1. Insect pollinators are required by all varieties, wind pollination alone giving unsatisfactory results.

2. All varieties give best results when crossed with an effective pollinizer.

3. Only the Baldwin yields a commercial crop when self-pollinated and even the Baldwin gives better results when crossed with an effective pollinizer.

STUDIES IN INTER-FRUITFULNESS OF APPLE VARIETIES

During the past four years very many extensive crosses and self-pollinations have been made with standard varieties grown in Nova Scotia and much information with respect to the value of varieties from the standpoint of self-fruitfulness and of cross-fruitfulness have been obtained. It is not necessary

to detail the results of these experiments, but rather to point out the practical significance to the grower of the results secured.

A point of prime importance brought out in these studies was that from the standpoint of their value as pollen parents, *i.e.*, as pollinizers for other varieties, apple varieties may be sharply divided into two groups, namely, (1) good pollen varieties and (2) poor pollen varieties. The former may be usually depended upon to work well as pollinizers with other varieties that blossom at the same time. The latter ordinarily have little value as pollen parents, some of them producing in the variety pollinated even less fruit than when the variety on which this pollen is used is self-pollinated. Poor pollen producers may themselves be highly fruitful, when pollinated by one of the group of good pollen producers. The poor pollen producers are known not only by the small quantity of pollen produced of low germinability and inferior value for crossing purposes, but by their relatively low seed content as compared with good pollen producers. This point is of the utmost importance to the grower who has a pollination problem in his orchard or who desires to make new plantings. The practical results of our studies can best be appreciated by a study of the following table in which some of the common varieties are listed as good or poor apple producers. By consulting the blossoming chart in connection therewith, also the chart showing the inter-fruitfulness of some standard varieties and a third chart showing the results of hand-pollination experiments, together with the accompanying table of good and poor pollen producers, the grower can decide which varieties "go well" together and avoid those combinations that are sure to give inferior results. In providing pollinizers for varieties that have given poor results due to lack of pollination, it is preferable to choose a variety that blossoms a little later rather than a little earlier, because, in the first case, the pollen of the pollinizing variety will be liberated before that of the other is shed, thus facilitating cross-pollination. The blossoming chart shows only *average* blooming periods, but, in some seasons, there is much less overlapping than others, and the more long drawn out the bloom the greater likelihood of a pollination problem arising, unless adequate provision has been made.

TABLE No. 2.—CLASSIFICATION OF APPLE VARIETIES

Poor pollen producers	Good pollen producers
Baldwin	Alexander
Blenheim	Ben Davis
Bramley Seedling	Bough Sweet
Gravenstein	Cortland
King	Cox Orange
Mann	Crimson Beauty
Nonpareil (Roxbury Russet)	Duchess
Ribston	Dudley
Rhode Island Greening	Delicious
Stark	Fameuse
	Gano
	Golden Russet
	Grimes Golden
	Jonathan
	McIntosh
	Rome Beauty
	Tolman Sweet
	Wagener
	Wealthy
	Wellington
	Winter Banana
	Wolf River
	Yellow Bellflower
	Yellow Transparent
	York Imperial

FIELD STUDIES IN INSECT POLLINATORS

As already clearly shown in the foregoing experiments, apple pollination is effected by insects, and it is usually claimed that the hive bee is the main agent in apple pollination. Unfortunately, our studies show that as a result of widespread poisoning from the use of poisoned sprays and dusts, the hive bee has ceased to be a factor in apple pollination in the Annapolis valley of Nova Scotia. The danger of poisoning hive bees may be reduced, though not entirely eliminated, by refraining from spraying and dusting during the blossoming period and by moving the bees into the orchard only when the early apples have come into bloom and removing them before the after-blossom sprays are applied. Dusting is usually more fatal than spraying, but severe losses may follow either practice when poisons are applied to apple bloom, or to the blossoms of other plants growing in or near the orchard.

Careful investigations have shown that pollination at present is mainly effected by various small, solitary bees that nest in the ground in the neighbourhood of orchards, especially along roadsides, pastures, dykes and similar situations. They have been reasonably plentiful in at least most orchards during the years 1928 to 1931 inclusive. In 1932, there was an apparent general decrease and this, combined with unfavourable weather for bee activity during the blossoming period, had a noticeable effect on fruit setting. Bumble bees, while sometimes abundant locally, were of minor importance in most orchards during the course of our studies.

While, therefore, under favourable conditions, solitary bees may alone be able to satisfactorily pollinate the apple crop, conditions may arise when it is desirable to supplement their efforts. This can only be done by supplying hive bees for the purpose.

It should be emphasized, however, that a few colonies of bees placed in an orchard surrounded by large acreages devoid of bees is of little or no value. In such situations it may be necessary to have a concentration of from 35 to 50 colonies in order to ensure the pollination of the particular orchard in which the bees are placed. In districts where beekeeping is general, however, and neighbouring orchards are similarly supplied, one colony to the acre or even one colony to four acres may be sufficient. Owing to the many factors involved more exact figures cannot be given. It must suffice to point out that the provision of as many colonies as practicable is a useful measure of insurance against unfavourable weather, and a scarcity of wild pollinators, since it is only the hive bees that can be increased in numbers at will and placed where needed in the orchards. Unfortunately, at the present time, there is no adequate local supply; inexperience in beekeeping and the danger of poisoning prevents many from adopting this practice who would otherwise do so.

ARRANGEMENT OF POLLINIZERS

In orchard planning, the mixture of self-unfruitful varieties should be avoided, and this includes practically all varieties, save Baldwin. A great deal of trouble is experienced with Blenheims planted in solid blocks. Not all Blenheims even in mixed orchards are fruitful, but more of them are, whereas we do not know of large unmixed blocks bearing regular crops. The same may be said of Starks. Large blocks of a single variety are uncommon in Nova Scotia and this has greatly reduced the trouble due to lack of pollination, but lack of bearing due to too many trees in a block has been noted, not only in the foregoing varieties, but also, though less commonly, in certain other varieties, including Golden Russet, Spy and Gravenstein.

Bad combinations of cross-unfruitful sorts are unfortunately more common and are especially to be avoided. Thus a combination of Blenheim and Baldwin is bad, because though tbe Baldwin may give fair crops in its bearing years,

though probably less than in a block by itself, the Blenheim is entirely without a suitable supply of pollen, and, being very self-unfruitful, is likely to give very inferior results. Stark and Baldwin or Stark and Blenheim is another bad combination and, worse still, a combination of all three. With King the pollen variety seems to make less difference than with most others. This variety *typically producing a low percentage of fruit, no matter what pollen parent* is used, nevertheless is commercially fruitful because of its heavy blossoming habit, large size and annual bearing habit. However, even King responds by increased yields to an effective pollinizer, but is itself of little use as a pollen parent. Therefore, where King occurs in planting, a suitable pollinizer must be provided and the same may be said of Gravenstein and other poor pollen producers.

Furthermore, it must be borne in mind that, when supplying a pollinizer *for a variety that itself is a poor pollen producer, a third variety must be used* that is cross-fruitful with the first pollinizer.

The accompanying plans showing method of setting out a four-variety block and for grafting-out a solid block of one variety will be suggestive of many similar combinations that may be used.

OTHER CAUSES OF UNFRUITFULNESS

It should be emphasized that lack of pollination is but one of the causes of unfruitfulness; lack of adequate attention to fertilizer requirements and damage caused by insect or fungous pests being of most importance. Furthermore, vigorous fruit-spurs are more likely to set fruit with less pollination than weak spurs. Pollination alone, therefore, cannot ensure regular cropping, which can only be effected by attention to all the necessary details of good orchard practice.

APPLE POLLINATION STUDIES IN THE ANNAPOLIS VALLEY

FOREWORD

The investigations described in the following pages were undertaken as a result of resolutions received by the Honourable the Minister of Agriculture, from the Canadian Horticultural Council, the Nova Scotia Fruit Growers' Association and other organizations, requesting that an investigation be undertaken into the whole pollination problem in Nova Scotia and whether the alleged destruction of pollinating insects as a result of poison dusts had adversely influenced the setting of fruit during the past few years. Upon receipt of these resolutions a committee was appointed by the Deputy Minister to consider and report upon the advisability of initiating such an investigation. This committee was as follows:

- Arthur Gibson, Dominion Entomologist (Chairman)
- W. T. Macoun, Dominion Horticulturist
- C. B. Gooderham, Dominion Apiarist (Secretary)
- H. G. Crawford, Chief, Division of Field Crop and Garden Insects, Entomological Branch
- F. A. Herman, Division of Chemistry, Central Experimental Farm
- H. Groh, Division of Botany, Central Experimental Farm

As a result of the deliberations of this committee a report was prepared for the Deputy Minister approving the carrying out of the proposed investigation, but recognizing that factors affecting the set of fruit other than insects, would have to be taken into consideration in the course of such studies, they expressed the opinion that such an investigation could not be completed in less time than five years and drew up a tentative scheme for the conduct of the experiments. They further recommended that Dr. W. H. Brittain, Professor of Entomology, Macdonald College, be asked to take over the general supervision of the experiments, working in co-operation with the officials of the Dominion Department of Agriculture, whose work had a direct bearing on the problem involved. It was understood that the problem would not come under any one Branch, but that the officer in charge would attempt to co-ordinate the work of the different agencies concerned. The Department of Agriculture for Nova Scotia took an active interest in planning the work, and the Deputy Minister, Col. R. Innes, placed an assistant and office facilities at the disposal of the committee.

The foregoing plan having received the approval of the Deputy Minister and the sanction of the Minister, was proceeded with and an effort made to devote as much attention as possible to the significant factors involved in apple pollination. The study falls naturally into two parts: first, a study of the inter-fruitfulness of some of the chief commercial varieties grown in Nova Scotia and, second, a study of the insects involved in the pollinizing process. While the study dealt primarily with local varieties and problems an attempt was made to pay particular attention to a study of factors and principles applicable to all work of this sort.

Considerations of space have forbidden the publication of a great deal of data secured during the course of these investigations, some of which have an important bearing on the work. For this reason much tabular matter, weather records, results of analyses and other matter has had to be excluded, while detailed accounts of other phases of the work will be published in separate papers.

The five-year period has proved sufficient to elucidate most of the problems dealing with the inter-fruitfulness of the apple varieties studied, and to throw some light upon the general problem of apple pollination. A number of points of considerable theoretical importance, as indicated in the following pages, still awaits attention. It is to be regretted that lack of time, the necessity of developing a suitable technique, want of suitable equipment, poisoning of our experimental apiaries and other causes have not permitted us to bring the entomological phases of the investigation to the same degree of completeness. Consequently many of the conclusions must be regarded as tentative.

ACKNOWLEDGMENTS

Grateful acknowledgment is due from the officer in charge of these investigations to colleagues and assistants who have helped him in securing the data contained herein. The names of several appear as joint authors of sections of this report, while the assistance of others is acknowledged elsewhere.

Mr. F. A. Herman was associated in the poisoning investigations; Mr. C. B. Gooderham in the utilization of hive bees in orchards; Mr. Don Blair in studies of inter-fruitfulness of apple varieties; Mr. J. M. Cameron in studies of the activities of hive and wild bees and Mr. C. A. Atwood in studies of the biology and classification of insect pollinators.

At the outset of the investigation it was necessary to proceed with improvised methods and a temporary staff and through the course of the work this occasioned many difficulties. Nevertheless, the smoothness with which the work proceeded after the first year, speaks very well indeed for the industry and initiative of the various workers. It would be difficult to imagine a temporary organization working together more smoothly in carrying out the work for which each was responsible in connection with this complicated problem.

In addition to those who have been solely or jointly responsible for definite parts of the investigation, it would be impossible to mention by name all those whose efforts have been placed freely at our disposal in the course of these studies. Dr. W. S. Blair, Superintendent of the Experimental Station, Kentville, took a keen personal interest in the work and without his continuous assistance an important phase of our studies could never have been carried out. His efforts were ably seconded in many ways by those of his assistant, Mr. C. C. Eidt. Special thanks are also due to Mr. F. H. Johnson for invaluable assistance during four years of the investigation; to Mr. R. D. L. Bligh for direction of pollination crew during 1928; to Mr. Evan Craig and Mr. H. G. Payne for essential advice and assistance in connection with apicultural problems; to Messrs. Robert Longley, John Leefe, and Robert Ward, who assisted at various times in connection with certain phases of the problem. Mr. A. Hill gave invaluable assistance and advice in the initial year of the investigations. Various members of the staff of Acadia University, including Dr. H. G. Perry, Dr. H. W. Harkness, Dr. D. V. Hill, assisted with equipment or advice, while Dr. Muriel V. Roscoe carried out essential cytological studies in connection with the chromosome count of apple varieties. Permission to use unpublished data secured in these studies was kindly furnished by Dr. Roscoe. Mr. J. F. Hockey of the Dominion Laboratory of Plant Pathology extended co-operation in the form of the use of equipment, laboratory space and personal assistance. Mr. M. B. Davis, the Dominion Department of Agriculture, and Dr. C. L. Huskins, of McGill University, read and

criticized parts of the report. In the studies to determine sources of bee poisoning the assistance of Mr. H. Groh was invaluable. Mr. J. Patterson assisted us with the loan of the solar radiation apparatus used in our experiments and Dr. W. J. Rowles of Macdonald College designed and prepared the photoelectric bee counter. Mr. W. E. Whitehead is responsible for most of the illustrations used in the report. To all members of the Committee, especially those who actively assisted in the investigation, the officer in charge extends his sincere thanks.

I. INTRODUCTION

W. H. BRITTAIN

A. THE APPLE INDUSTRY IN NOVA SCOTIA

1. GEOGRAPHICAL POSITION

The province of Nova Scotia consists of a peninsula projecting into the Atlantic ocean, together with the island of Cape Breton. It lies in a northeasterly and southwesterly direction and is nearly 400 miles in length. The forty-fifth parallel of north latitude divides the province into two nearly equal parts. The " fruit belt " lies in the western part, mostly south of this parallel,

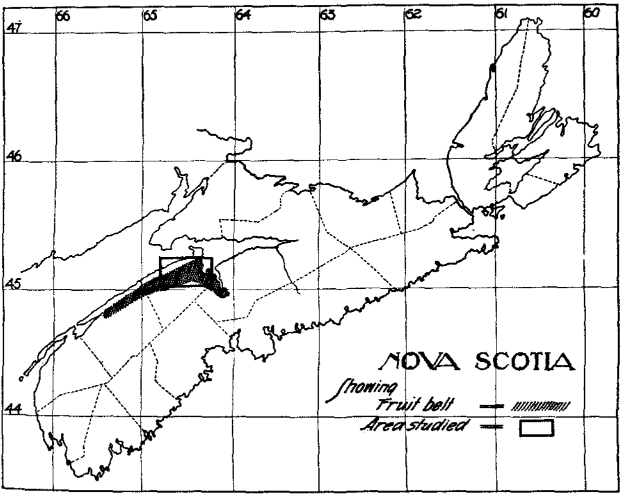

FIG. 1.—Map of Nova Scotia showing fruit belt (original).

in what is generally called the "Annapolis valley," though this district really comprises the valleys of several streams emptying into the bay of Fundy, including the Annapolis, Cornwallis, Gaspereaux and Avon rivers. A range of hills 500 to 700 feet in height called the North Mountain, protects the Valley from the north and northeast winds and forms the northern boundary of the Valley,

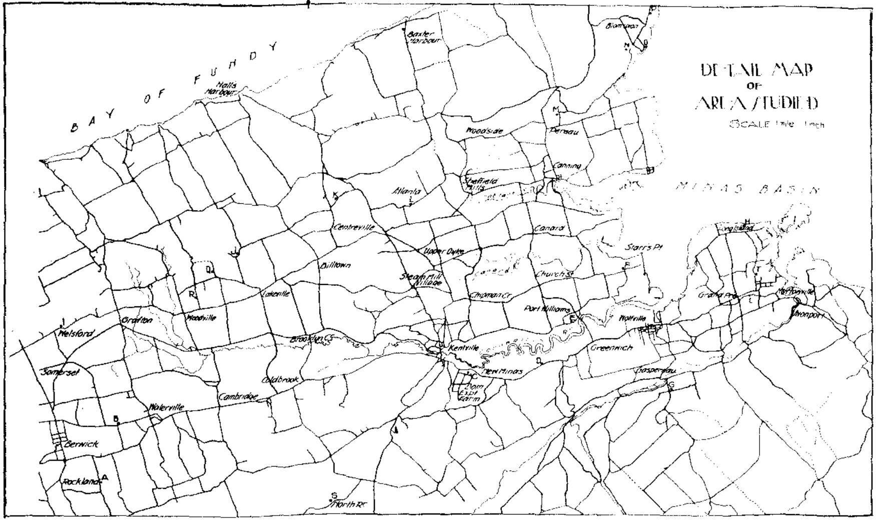

Fig. 2. Detail map of area studied (original)

while a corresponding range of hills, called the South Mountain, shuts it in on the south. The extreme eastern and western limits are marked by the towns of Annapolis Royal on the west and Windsor on the east. Of course there are apples grown outside of this area, but, in the main, fruit growing on a large commercial scale is largely confined to this territory. Here we have concentrated in a valley about 100 miles long and varying in width from five to ten miles, an acreage in apple trees of approximately 38,000 acres.

2. CLIMATE

Fraser (1924), in discussing the situation of important apple growing regions of North America, states as follows:—

"The variation between the day and night temperatures in New Jersey, Delaware and the eastern part of Maryland and Virginia is about the same as that along the shores of lake Ontario. In both instances we find fruit regions of the highest rank. *The Annapolis valley in Nova Scotia,* alongside the bay of Fundy, the eastern shore of lake Michigan and the Pacific coast states are all fruit regions because of their climate."

Writing regarding general climatic conditions of Nova Scotia, W. A. Middleton, Provincial Horticulturist, states:—

"Extreme heat or cold is not experienced in the commercial apple area of the province. The summer temperature occasionally rises to about 90 degrees, while that of the winter seldom falls below zero. The average summer temperature is 62 degrees, that of the winter about 25 degrees, and the mean annual temperature about 43 degrees. The annual rainfall ranges from 40 to 45 inches and is generally well spread over each month of the year."

Further details regarding climate are given elsewhere.

The soil varies from a light sandy loam to clay loam. Along the North Mountain range and at the east and west ends of the Valley the heavier soils predominate, while elsewhere lighter soils are more in evidence, some of the lightest soils being in the centre of the Valley.

3. VARIETIES GROWN

Comeau (23) gives the following partial list of apple varieties grown in the Valley:-

"Alexander (Emperor)
Allington Pippin
Arabka
Arkansas Beauty
Baldwin
Baxter
Ben Davis
Bethel
Bietigheimer
Bismark
Blenheim Orange Pippin
Bottle Greening
Borkins
Bough Sweet
Bramley Seedling
Calkin Pippin
Canada Baldwin
Canada Red
Chenango Strawberry
Clayton
Clyde Beauty
Charles Ross
Colvert
Cooper's Market
Cornish Aromatic
Cortland
Cox Orange
Cranberry Pippin
Crimson Beauty
Duchess
Dudley
Danvers Sweet
Delicious
Early Harvest
Esopus Spitzenburg
Fall Pippin
Fallawater
Fameuse (Snow)
Gano
Gilliflower
Gideon
Gloria Mundi
Golden Pippin
Golden Russet (American)
Golden Russet (English)
Golden Sweet
Gravenstein
Grimes Golden
Haas (Fall Queen)
Honey Sweet (Winter Sweet Paradise)
Hubbardston
Hublon
Hunt Russet
Hurlbut
Ingram
Jacob Sweet
Jenneting
Jersey Sweet
Jewett Red
Jonathan
Jones
Kent Pippin
Keswick Codlin
Kitchener
King
Lady Finger
Lady Sweet
Late Strawberry
Longfield
Longworth
Louise (Princess Louise)

3. **VARIETIES GROWN**—*Concluded*

McIntosh
McMahon
Maiden Blush
Mann
Mother
Newtown Pippin (N.Y. Pippin)
Nonpareil (Roxbury Russet)
Northern Spy
North West Greening
Ohio Pippin
Ontario
Orange (of New Jersey)
Patten Greening
Pewaukee
Peck Pleasant
Pennock
Pine Apple
Porter Pippin
Pound Sweet
Pumpkin Sweet
Red Streak
Red Sweet Pippin (Moore Sweet)
Red Russet
R.I. Greening
Ribston Pippin
Rolfe
Rome Beauty
Rose Red
Salome
Scarlet Pippin
Scott Winter
Seek-no-further (Westfield)
Shackleford
Shiawassee
Smokehouse
Stark
Sutton Beauty
Swaar
Swazie
Sweet Greening
Thompson
Tolman Sweet
Twenty Ounce (Cayuga Red Streak)
Twenty Ounce Pippin
Vandevere (Newton Spitzenburg)
Victoria
Wagener
Wealthy
Wellington
Western Beauty
White Apple
White Craft
Winesap
Williams' Favorite
Wilson's Red June
Winter Banana
Winter Bough
Winter Pippin
Wolf River
Yellow Bellflower (Bishop Pippin)
York Imperial"

"Of these varieties, the following, arranged approximately in the order of ripening, are of commercial importance in the fruit district of Nova Scotia:

Crimson *Beauty*
Yellow Transparent
Red Astrachan
Duchess of Oldenburg
Williams' Favorite
Wealthy
Gravenstein
Dudley
Alexander
Wolf River
McIntosh
Blenheim
Ribston
King
Bishop Pippin
Wagener
Cox Orange
Wellington
R. I. *Greening*
Baldwin
Stark
Northern Spy
Fallawater
Golden Russet
Nonpareil
Ben Davis"

"The following varieties are important in the export trade of the province:

Gravenstein
Blenheim
Ribston
King
Wagener
Cox *Orange*
Wellington
R. I. Greening
Baldwin
Stark
Northern Spy
Fallawater
Golden Russet
Nonpareil
Ben Davis"

"The ten best commercial varieties for export are as follows:

Gravenstein
Blenheim
Ribston
King
Wagener
R. I. Greening
Baldwin
Northern Spy
Golden Russet
Nonpareil"

The officially recommended varieties for commercial plantings are as follows:

Gravenstein (Crimson)
Cox Orange
Golden Russet
King (Red)
Spy (Red)
Baldwin

McIntosh is favoured by some authorities, but mainly for local demands.

The standard varieties that are recommended to be retained, but not recommended for future planting are as follows:

Ribston Pippin
Blenheim Orange
Stark
Greening
Nonpareil
Wellington
Wealthy
Bramley *Seedling*
Wolf River
Gano
Ben Davis

Of the foregoing Wagener is favoured as a filler owing to the small size of the tree and the fact that it is a short lived tree. It has an additional advantage in being an effective pollinizer for the early varieties.

4. QUANTITY GROWN

The following tabulation taken from official sources indicates the growth of the apple industry for the past half century:

	Barrels
1880-85—Annual Average	30,320
1885-90— " "	83,356
1890-95— " "	118,556
1895-1900— " "	261,879
1900-05— " "	377,225
1905-10— " "	496,655
1910-15— " "	786,633
1915-20— " "	932,957
1920-28— " "	1,056,057
1929— " "	2,134,100
1930— " "	1,172,443
1931— " "	1,611,273

In this connection a tabulation of the actual produced crop of the different varieties grown in the Valley is of interest:—

PERCENTAGE CROP OF VARIETIES OF APPLES OF THE TOTAL CROP PRODUCED *IN NOVA SCOTIA (FIGURES BY UNITED FRUIT CO.)*

Gravenstein	13
Baldwin	13
Stark	10
Ben Davis	10
Odd varieties	9
Ribston	8
King	6.5
Northern Spy	6
Nonpareil (Roxbury Russet)	5
Blenheim	5
Golden Russet	5
Fallawater	2.5
Wagener	2
Gano	1.6
Greening	1.5
Wolf River	0.8
Wealthy	0.7
Bishop Pippin (Yellow Bellflower)	0.4
	100.0

On examination of these figures, it is apparent that approximately 25 per cent of the crop is Gravenstein, Ribston and King; 25 per cent Blenheim, Northern Spy, Nonpareil, Golden Russet, Fallawater and Wagener; 35 per cent Baldwin, Ben Davis, Gano and Stark, and 15 per cent other sorts. This shows that 85 per cent of the crop is made up of what we consider 13 standard sorts.

From the foregoing data it is seen that a very large number of varieties are grown in Nova Scotia. One of the chief problems of the fruit industry is to reduce the number of unprofitable varieties, but it is only within recent years that the movement to cut down the number of varieties planted and to graft out the non-commercial and unprofitable sorts has gained headway. In connection with this movement it is of interest to note that 85 per cent of the crop is made up of what may be considered standard varieties.

5. AVERAGE YIELDS

It has been estimated that in the period 1900-1905 the average yield of apples in Nova Scotia was 16 barrels per acre; in the period 1910-1915 it was 24½ barrels per acre, while the average annual yield in the years 1920-1926 was 30 barrels per acre. Included in these figures there is, of course, a large acreage of small, non-commercial orchards, though, even with all allowances, the average crop must be regarded as small. The figures for a number of typical orchards from central Kings county, which is the most typical orchard section,

including both poorly cared for and well cared for orchards, indicate that in really commercial orchards the crop is much more satisfactory.

An examination of the figures shows that, in the period under study, the yield per acre varied from 26 to 172 barrels, while the average for all these orchards was considerably higher than the average yield for the province, viz., 66·6 barrels. Average yields of from 80 to 100 barrels per acre are considered necessary for profitable fruit growing and several orchardists have attained this figure, but the number that fall below this amount materially lowers the average figures.

B. FACTORS OTHER THAN POLLINATION AFFECTING FRUIT PRODUCTION

1. GENERAL

Since this report is concerned with the problem of pollination, it is not necessary to deal exhaustively with other factors involved in the setting or production of apples. Nevertheless, a brief discussion of certain of the more important factors involved in this process, may enable us better to appreciate the relative importance of the pollination factor and the phenomena associated therewith, and the better to evaluate the results of the pollination studies described herein.

It is well known to all students of the subject that the production of profitable crops of marketable fruit is the end result of a long series of factors. Pollination is but a link, though a very important link, in the chain. Some of these factors are at least partially under the control of the grower; many are not. The proper procedure for every fruit-grower should be to keep all conditions as favourable as possible for the production of large crops of quality fruit, so that, through neglect to attend to a single factor, he may not lose not only his crop, but also the money spent in attempting to produce it. The proper attention to all factors within his power to control may enable him to reduce or minimize the losses resulting from unfavourable conditions not directly controllable.

In order to secure dependable data with regard to all measurable and relevant factors we have tabulated the weather records for the growing season over a period of years and have attempted to analyze these data from the standpoint of the possible effect upon fruit setting and fruit production. An intensive study of 16 representative orchards situated in central Kings county has also been made over a three-year period in an attempt to determine, if possible, the effect of various cultural practices. In addition, the crop returns of 34 growers for a period of six years were compiled and studied in connection with their expenditure for spray material, fertilizer, etc., as obtained from the records of a local fruit company. Furthermore, an economic survey of approximately one hundred orchards in the same district was made. In this survey special attention was again given to the question of fertilizer and spraying practices, as these factors lent themselves well to statistical treatment and gave indication of being of considerable importance in connection with the quantity of apples produced. These surveys were carried out by Mr. Robert Longley of the Provincial staff and only the more outstanding and general conclusions are referred to in this report. The results obtained are in general agreement with the more prolonged studies conducted by the Economics Branch of the Dominion Department of Agriculture and reported by Coke (1931).

2. CLIMATIC FACTORS

The most important factor, or rather complex of factors not under the control of man is that conveniently summarized under the heading of " climate ". The effect of certain climatic factors is easy to observe, but, in the main, these factors are difficult to measure and hard to evaluate.

The effect of climate can best be discussed with reference to (1) its direct effect upon the blossoms, or (2) its indirect effect upon the insect pollinators. Of these the second is probably more important, but since this problem is discussed at great length elsewhere, it is merely referred to at this point.

(*a*) WEATHER CONDITIONS DURING BLOOM

Careful records of weather during the blossoming period have been kept for a number of years, but it is difficult to establish significant correlations between such conditions and the set of fruit, probably because conditions at a certain critical period such as the period of stigma receptivity may be the crucial factor and our methods have not achieved a sufficient degree of refinement to demonstrate this. However, certain facts are sufficiently clear to deserve mention.

Frost during the bloom may result in the destruction of the stigmatic surfaces of the pistil followed by the subsequent drop of the blossoms. Such frosts are of comparatively rare occurrence in most parts of the Valley. Since the inception of this investigation, no such losses have occurred in a series of orchards in which observations have been made, except in one case in 1932 in an orchard known to be in a " frost belt ". Such conditions do occasionally occur, particularly in certain sections in the centre of the Valley. It has been pointed out (Murneek, 1930) that frosty weather at bloom, even where it does not kill, may prevent the growth of the pollen tube.

Hedrick (1908) contends that a temperature slightly above the average is usually most favourable for fruit setting. On the other hand, a very high temperature, especially if accompanied by wind, may bring about the drying up of the stigmas, so that they remain receptive for but a short time. It was noteworthy that in the season of 1930 the blossoming period was coincident with a very high temperature and a short period of stigma receptivity was noted by all workers, whereas, during the cooler, more humid season of 1931, the period of stigma receptivity was longer. Knowlton (1929) states that, " it is an established horticultural fact that a larger set of fruit occurs on selfed varieties in seasons when the temperatures are most favourable for pollen tube growth." When we study the wide range of self-fruitfulness that may occur in the same variety from year to year, we are forced to believe that this must be the case. This was particularly noticeable in Blenheim in the favourable blooming period of 1931. We had become accustomed to regard this variety as almost completely self-unfruitful, but in 1932 selfing produced a fruit set of up to five per cent.

Excessive humidity and driving rains during bloom appear to have an adverse effect upon the pollen, which may be washed away or deteriorate while still on the anthers, or they may even wash off pollen already deposited on the stigma. Low yields from certain varieties have been observed to follow periods of rainy weather during the blossoming periods of such varieties. The occurrence of high winds during bloom, often mentioned as a factor detrimental to fruit setting, has been a negligible factor during the course of these studies in four out of the five years, but in 1932 it appeared to be of importance in certain sections.

The fact that it may not be necessary for more than one blossom in twenty to develop into a marketable apple in order to secure a commercial crop, gives

a considerable margin of safety in apple growing, since, even though a large proportion of blossoms may be destroyed, the set may be sufficiently large, and, in many cases, larger than necessary for a commercial crop. This fact is brought out by the records of fruit setting for four standard varieties in sixteen orchards for the years 1928-1930 inclusive, taken together with the weather records for the same period.

TABLE No. 1.—RECORD OF PER CENT FRUIT OBTAINED IN SIXTEEN KINGS COUNTY ORCHARDS, 1928–1930

Variety	1928	1929	1930	Average
Gravenstein	3·98	5·64	7·05	5·86
King	5·10	4·49	7·79	5·68
Baldwin	6·90	11·32	10·20	9·92
Spy	7·08	9·13	10·65	10·12
Averages	5·76	7·64	8·92	7·64

NOTE.—"Per cent fruit" refers to the percentage of blossoms that produced fruit which remained after the "July drop". Figures based on counts of approximately 1,000 blossoms of each variety each year.

The figures would seem to indicate that in these orchards during the period studied the average set obtained was at least reasonably satisfactory. Unfortunately, this period does not include a season similar to 1932, when conditions for pollination were very unfavourable owing to the very broken weather. It would be expected that under such conditions failure to set through lack of a proper distribution of pollinizing varieties and an inadequate force of insect pollinators would be accentuated.

(b) WEATHER CONDITIONS AT OTHER PERIODS

Winter injury to trees of the ordinary commercial varieties is not common in the fruit belt of Nova Scotia, but freezing weather that occurs after the buds have started in the spring but before the blossoms open, may act directly on the blossoms, destroying the essential parts of the flower. Indirect injury resulting in a reduced crop may be caused by frost injury to the developing leaves. Such injury results in a dwarfing and curling of the leaf, which is inclined to be brittle and, not infrequently, the lower epidermis separates from the overlying cells. Such a condition was quite widespread in 1928 and occurred locally in 1932. It should be noted that the destruction of even a considerable proportion of blossom buds by frost, does not necessarily reduce the final crop, since sufficient may set from the uninjured buds to produce a commercial yield. The injury to the primary leaves is sometimes more serious and sometimes appears to result in an abnormal drop.

The climate of the Annapolis valley is ordinarily characterized by an adequate supply of moisture throughout the growing season, and protracted droughts resulting in dwarfing and even drop of leaves and fruit are comparatively rare. They are, however, not entirely unknown, as, for example, in the seasons of 1921 and 1928, where orchards on dry land suffered badly, in some cases, and again in 1930, when a dry period of about eight weeks during the autumn months resulted in considerable dwarfing of the fruit.

Prolonged periods of rainy weather have rarely been mentioned as a cause of crop reduction. It would appear, however, on the basis of data secured during these investigations that the effect of excessive rainfall during the growing season had a detrimental effect on crop production, whereas the greater the sunlight during the months May to July inclusive, the more favourable the condition for fruit production. An extended discussion of this problem, however, is beyond the scope of this paper.

All the preceding discussion has had to do with the effect of weather conditions on the crop of the corresponding year. That the climatic complex also has an effect upon the crop of subsequent seasons is equally true, though the relative importance of the different factors is hard to evaluate. The fact that, in certain seasons, apple trees everywhere, even wild or uncared-for trees, bloom heavily, as in 1929 and in 1931, is indicative of the effect of little understood climatic factors in fruit-bud formation and vigour.

Significant weather records are presented in table 2, together with crop figures for the corresponding years.

TABLE No. 2.—WEATHER CONDITIONS FOR GROWING SEASON

Year	Barrels	Per cent possible bloom (estimated)	May-July (inclusive) and April-October (inclusive)					
			Mean temperature	Total rain (ins.)	Total sunlight (hrs.)	Mean temperature	Total rain (ins.)	Total sunlight (hrs.)
1915	613,882	?	55·73	12·05	593·5	54·5	23·09	1,271·9
1916	631,470	60	55·79	6·67	611·9	54·6	28·04	1,403·5
1917	774,730	80	56·65	8·90	513·2	53·0	27·35	1,230·4
1918	827,693	45	59·11	7·85	667·0	54·8	21·94	1,434·6
1919	1,600,000	90	58·17	6·44	688·8	54·4	16·09	1,357·8
1920	1,167,000	65	56·20	6·00	792·1	54·73	17·03	1,528·1
1921	2,000,000	85	58·17	5·34	700·4	55·92	13·98	1,511·3
1922	1,800,000	80	57·82	9·14	599·4	56·14	21·37	1,255·5
1923	2,021,177	90	55·64	7·26	625·6	53·30	20·92	1,350·4
1924	1,976,340	85	59·07	5·55	762·6	54·80	18·55	1,492·7
1925	1,447,401	75	58·88	10·77	652·7	53·53	22·88	1,378·7
1926	1,033,021	65	55·17	9·73	668·9	52·18	19·93	1,420·4
1927	1,086,932	85	56·67	10·37	665·3	54·24	30·11	1,405·7
1928	1,244,987	45	58·70	7·44	631·2	55·50	18·33	1,310·3
1929	2,134,100	95	59·34	9·26	775·5	55·57	19·89	1,459·0
1930	1,172,443	65	61·66	6·33	658·1	56·05	13·58	1,509·6
1931	1,611,273	95	59·75	7·73	620·3	56·23	21·64	1,321·5
1932	....	60	....	....	....	....	....	....

3. NUTRITIONAL FACTORS

The question of the nutritional factors that affect fruiting is too technical for extended treatment in a paper dealing with pollination and is neither necessary nor desirable. Nevertheless, it is evident that the set of fruit may be influenced jointly by pollination and a number of these other factors. Trees lacking in vigour are incapable of setting large crops whether pollinated or not, and it is not surprising that many workers have stressed tree vigour, and, more especially, fruit-spur vigour, as a factor in fruit setting. This factor is important because vigorous spurs can better supply an abundance of water and organic nutrients to the developing fruit. MacDaniels and Heinicke (1929) present evidence to show that there may be greater need for cross-pollination, which is usually a requisite for seed formation, when the trees have produced a large proportion of weak spurs, or when they are growing under conditions which otherwise limit the sap and nutrient supply to flowers and young fruits. The maintenance of a high level of nutrition may partially compensate for imperfect pollination or for irregularities in chromosome behaviour at megasporogenesis as Howlett (1932) contends.

Lattimer (1931) noted in pollination experiments conducted by him, that, in less vigorous trees there is a greater difference in relative effectiveness between the better pollinizers. On more vigorous trees there was little difference between the several good pollinizers used. The conclusion is drawn that when low-vigour trees are to be pollinated one should choose only an effective pollinizer. The different results obtained on various trees and between different limbs of the same tree have been brought out repeatedly in our tests.

Sandsten (1909) has recorded that the condition of the tree may have an important bearing on the quality of the pollen, it being inferior from orchards in poor cultural condition. Tree and fruit-spur vigour is the result of proper nutrition and this has to do with cultural practices and the maintenance of a suitable supply of moisture and nutrients. The importance of an adequate supply of nitrogen and the question of maintaining a correct proportion between the nitrogen and carbohydrates in the plant, is a matter to which much attention has been given during the past few years. The varying results obtained from tests with the same pollen on different limbs and even on different spurs emphasize the importance of the factor of vigour.

Anything that upsets this balance in the tree has a tendency to reduce fruit setting, though judicious pruning may increase it. Excessive applications of nitrogenous fertilizer, if ever given, appear to be rare. Our surveys indicate that applications of from 500 to 600 pounds per acre not only tend to increase setting, but are commercially profitable. The coefficient of correlation existing between the applications of commercial nitrogenous fertilizer, mainly in the form of nitrate of soda, and crop produced was ·4844 ± ·0527 for the orchards used in our economic survey. It is believed that this correlation would have been much higher, if allowance could have been made for the effect of previous crops. All data secured tend to emphasize the value of an adequate supply of readily available nitrogen. Our figures indicated no value as far as crop was concerned for nitrogen applied in the form of barnyard manure, though the presence of an adequate supply of organic matter in the soil is undoubtedly beneficial and should by no means be neglected in actual orchard practice. Otherwise, the beneficial effect of commercial nitrogenous fertilizer may not be experienced. Regarding the value of other types of fertilizers we do not have sufficient information from our own studies, though the advantage of using a balanced fertilizer has been insisted upon by certain investigators. That low phosphorus may be an important limiting factor has been demonstrated in other tests.

Our survey indicates that good crops are possible both under conditions of sod mulch or clean culture, if properly carried out, and any system of treatment that results in a strong growth of spurs and provides for an accumulation of stored food materials in the spur, is considered to favour fruit setting. Best crops are secured where the trees produce a good growth of leaves, terminal growth and trunk.

4. PATHOLOGICAL FACTORS

Under this heading we consider the injuries caused by insects and fungous pests. These may influence the crop indirectly by injuring the leaves, resulting in dwarfing or even drop of fruit, or they directly injure the blossoms or the fruit itself. The apple scab organism (*Venturia inaequalis* (Cook) Winter), is one of the most important orchard pests. Not only do heavy infestations result in leaf-injury, causing, in severe cases, dwarfing and partial defoliation, but early infection causes drop of blossoms or young fruit by its development upon the flower stalks.

Of the insects responsible for reducing fruit setting the green apple bug (*Lygus communis* Knight), is of most interest from our standpoint, because, owing to its small size, it is often overlooked and its injury attributed to other causes, including lack of pollination. The bud-moth (*Tmetocera ocellana* Schiff.), also deserves special mention. Many other pests might be mentioned in this connection, but those already indicated are sufficient for purposes of illustration.

A study of the yield records from sprayed and unsprayed orchards over a long period of years, shows a decided advantage in yield as well as in quality of fruit, in favour of the sprayed orchards. The result of our economic survey

showed a significant correlation between spray costs and yield, there being an upward trend of crops as the amount of spray materials used was increased. Confirmation of these results is obtained from a similar survey carried out by the Agricultural Economics Branch of the Department of Agriculture (Coke, 1931), in which it is likewise shown that crops and financial returns per acre increase with the amount expended upon pest control.

Against the beneficial effects of spraying and dusting must be set the injury that occasionally results from the use of certain spray schedules, but an examination of our figures proves that even those materials reputed to be most dangerous, show, over a period of years, a significant increase in crop over untreated trees.

The indirect effect of poison applications to bloom upon insect pollinators is discussed at length elsewhere, but the effect of the not uncommon practice of applying a fungicide dust during bloom, especially in seasons when the blossoming period has been prolonged, may be conveniently referred to at this point. The apparent injurious effect upon stigmas and anthers of applications of various fungicidal and insecticidal preparations has long been noted. In 1930 an application of sulphur dust to Golden Russet in our experiments reduced the original set by about 10 per cent but did not lower the final fruit yield. Since apple trees do not bloom evenly, only a certain proportion of blossoms are in a condition to be injured at any one time. Therefore, the destruction of a certain proportion of blossoms may even be beneficial in imparting greater vigour to those that remain, as shown by MacDaniels and Furr (1931) in the case of sulphur dust. If, on the other hand, the application is made early, before many blossoms are pollinated, or before the pollen tube has penetrated the style sufficiently to be beyond the effect of the sulphur, an injurious effect upon set may result on certain varieties. Also with varieties that tend to produce only one or two fruits to the spur such as King, the result may be more serious than on varieties that tend to set in clusters, as Wagener, Baldwin, etc.

II. POLLINATION AND FRUITFULNESS IN APPLES

W. H. BRITTAIN

A. THE PROCESS OF POLLINATION AND FERTILIZATION

(*Definitions*)

Since there has been some lack of uniformity in the nomenclature used in connection with pollination work the following definitions of terms, as employed throughout this paper, are given:

Pollination.—The mere transfer of the pollen from anther to stigma constitutes *pollination* and is usually effected by the aid of insects. The transfer of pollen from the anther of one flower of one variety to the stigma of another *of the same variety* is known as *self-pollination*. The transfer from the anther of one flower of one variety to the stigma of another is *cross-pollination*.

Pollinizer.—The male parent, that is, the plant that furnishes the pollen.

Pollinator.—The agent for distribution of the pollen.

As all investigators have shown, the chief agents in the transfer of pollen from one flower to the other, are insects. A certain amount of apple pollen is, it is true, carried by wind, as will be discussed at greater length elsewhere, but wind pollination as far as the apple is concerned, is negligible. In the absence of the hive bee over wide areas of our fruit belt, this role is performed largely by wild bees, mostly of the genera *Halictus* and *Andrena*, though certain species of flies and certain other insects play a minor part.

Fertilization.—Following pollination with the pollen of a suitable variety, the pollen tube develops, grows down the style through the tissue and finally reaches the ovary, where, upon penetration of the ovule, the sperm is discharged into the embryo sac, where it unites with the egg cell, thus accomplishing *fertilization*, this process usually resulting in the formation of seed. This initiates growth and development of the fruit and is requisite to setting. Where the ovules fail of fertilization, or where, for any reason development is checked the blossoms are usually shed.

Fruitful.—A plant which produces mature fruit is said to be fruitful. As ordinarily used it means sufficient to produce a commercial crop.

Self-fruitful and *Self-unfruitful.*—From the standpoint of their requirements for pollination apples may be either (1) *self-fruitful* or (2) *self-unfruitful, i.e.* (1) they are capable of producing mature fruit when pollinated with their own pollen or (2) they require the pollen from another variety in order to produce fruit. We shall see later that few, if any, varieties are completely self-unfruitful, and hence the expression " partially self-fruitful " largely loses its meaning. In fact, self-unfruitfulness is rarely completely expressed in the apple, as pointed out by Crane and Lawrence, varying from varieties that yield little or no fruit when self-pollinated to others that produce a set little short of that obtained from favourable cross-pollination.

Cross-fruitful and *Cross-unfruitful.*—When the pollen from one variety results in fruit production when placed on the stigma of another variety, the first variety is said to be *cross-fruitful* with the second variety. On the other

hand, if fruit does not result the condition is known as *cross-unfruitful.* Just as few apple varieties are completely self-unfruitful, so there will be few cases in which the pollen from one variety is completely useless for another variety, though there are many combinations that give very poor results commercially. Therefore, the expressions "commercially self- or cross-fruitful" would be more accurate.

Sterility.—The condition in which there is failure to set fruit with viable seed.

Self-sterile and *Self-fertile.*—The terms *self-sterile* and *self-fertile*, often used synonymously with self-unfruitful and self-fruitful respectively, are more properly applied to the ability or inability of the plant to produce fruit with viable seeds when self-pollinated. Since fruits may be obtained which produce no viable seeds in the case of certain apple varieties, such a variety may be self-fruitful and, at the same time self-sterile, at least theoretically. The production of viable seedlings is, of course, an all-important factor in breeding work, but is not of direct interest in connection with pollination experiments, except in so far as the production of viable seeds is to be correlated with the value of certain varieties as pollinizers for other varieties.

B. THE POLLINATION PROBLEM

It will be clear from the foregoing that the pollination problem in commercial orchards consists (1) in planting together varieties that are inter-fruitful, *i.e.*, in which each variety has another blooming at the same time that can be depended upon to pollinate it, or (2) in "working over" a sufficient number of trees in blocks of self-unfruitful or cross-unfruitful varieties to secure adequate pollination, or (3) in supplying insect pollinators where they are not present in adequate numbers.

It has been shown that, in Nova Scotia, a great many varieties are grown and most of the older orchards are planted to a large number of varieties. While this has been a very serious drawback from a commercial standpoint, it has resulted in the pollination problem being less serious than in many other districts, where the exclusive growth of a few commercially desirable sorts has been the rule. In many of these orchards, for practically all varieties there are present others with which they are cross-fruitful. In other cases, the mixture of varieties, from the standpoint of pollination, has been unsuitable and has undoubtedly resulted in subnormal crops, especially in years in which conditions for cross-pollination were unfavourable. Such subnormal crops over a long period of years may well result in a large aggregate loss to the grower. In a few cases large blocks of self-unfruitful varieties have been set out. A good example is Blenheim, which is one of the most self-unfruitful of locally grown apple varieties. Owing to its resistance to apple scab, numbers of growers set out blocks of this variety, with the result of poor and infrequent crops. Considerable difficulty has also been experienced with Stark, Ben Davis and, to a lesser extent, certain other varieties. With the recent movement to restrict new planting to a few of the more profitable varieties and to graft out unprofitable ones, comes the need for closer attention to the question of pollination. One object of these studies is to determine the inter-fruitfulness of the varieties that are now recommended for planting in the Annapolis valley. Two other varieties, viz., Blenheim and Stark, frequently reported as unfruitful, have also been given special attention. Furthermore, it has been considered desirable to make a thorough study of insect pollinators, to determine whether the natural supply is sufficient or whether means should be taken to increase their number. In this connection a study of poisoning among hive bees as a result of orchard spraying and dusting practices has been made.

C. CAUSES OF UNFRUITFULNESS

According to Crane and Lawrence (1929 & 1930), unfruitfulness in apples is associated with (1) *generational sterility, i.e.,* the failure of any of the processes concerned in the normal alternation of generations, viz., development of pollen, embryo sac, embryo, endosperm and the relation of these with one another, regardless of the cross made; (2) *morphological sterility* due to the suppression or abortion of the sex organs; (3) *incompatibility,* which is found in cases where both ovules and pollen are functional, the failure to set fruit being due to the fact that the pollen tube becomes arrested in the stylar tissue, whereas, in a compatible cross, with the same pollen and ovules taking part, the pollen tube travels the full length of the style, the male and female nuclei fuse and the fertilized ovule develops into a fruit. The term *incompatibility* has been often misused in horticultural literature, being applied to various forms of unfruitfulness in addition to that indicated; (4) *parthenocarpy* or the development of fruit without seed; (5) *number of seeds per ovary.*

Without embarking upon a complete discussion of the genetic constitution of apple varieties, it may serve to clarify future discussion to refer briefly to certain facts in connection therewith. We owe to several workers our present knowledge of chromosome behaviour in the apple (*vide* Kobel (1930, 1930a, & 1931), Rybin (1926), Nebel (1930), Darlington and Moffet (1930), Moffet (1931), Roscoe (unpublished data)). Darlington and Moffet (*loc. cit.*) show that the basic chromosome number in the Pomoideae is 17 and that diploid, triploid and tetraploid forms occur. These writers find, however, that the chromosome constitution of apples is complex. Thus so-called diploids with $2n=34$ are, in reality, secondary polyploids being hexasomic in respect to three chromosomes and tetrasomic in respect to four chromosomes. Triploids are partly hexasomic and partly nonasomic. Varieties with intermediate numbers are found, the highest frequency in triploid x diploid seedlings being 41. Among the commercial apples classified as diploids may be listed Cox Orange, Ben Davis, Spy, McIntosh, Duchess, Red Astrachan, Rome Beauty and Bishop Pippin; while Gravenstein, King, Baldwin, Blenheim and R. I. Greening are triploids, as indicated in the accompanying list. Consideration of the foregoing facts will shed considerable light on the results outlined in the following pages.

TABLE No. 3.—CHROMOSOME NUMBERS OF APPLE VARIETIES

Variety	Rybin	Kobel	Nebel	Darlington and Moffett	*M.V. Roscoe
Adersleben Calville			34		
Allington Pippin				34	
Annie Elizabeth				34	
Apfel aus Lunow			34		
Arkansas			51		
Baldwin		48-49	51	51	
Beauty of Bath				34	
Belle de Boskoop		46	51		
Ben Davis			34		
Blenheim Orange			51	51	
Bobnapfel		46-49			
Bramley Seedling				51	
Calville Grand Duke of Asden			34		
Carlisle Pippin				34	
Charlamowsky (Duchess of Oldenburg)			34		
Cox Orange Pippin				34	
Crimson Beauty					
Crimson Bramley				51	
Damason Reinette		45-47			
Deacon Jones					
Der Boehmer			34		
Delicious					

TABLE No. 3—CHROMOSOME NUMBERS OF APPLE VARIETIES—*Concluded*

Variety	Rybin	Kobel	Nebel	Darlington and Moffett	*M.V. Roscoe
Dolgo			34		
Doucin (Malling Type II)				34	
Early Victoria				34	
Eden			34		
Geheimrat Dr. Oldenburg			34		
Gelber Richard			34		
General von Hammerstein			34		
Genet Moyle				51	
Golden Russet					34
Gravenstein		45–46	51		
Gravenstein (several strains)			51		
Grenadier				34	
Grimes' Golden					34
Horbert's Reinette		45			
Irish Peach				34	
Jacques Lebel		49–51			
Jaune de Metz (Malling Type IX)				34	
Jonathan					34
Kentish				34	
Keswick Codlin				34	
Kola			68		
Lane's Prince Albert			34	34	
Lesans Calville			34		
Lord Derby				34	
McIntosh			34	42	
Macoun			34		
Manx Codlin				34	
Manks Küchenapfel			34		
Medina			34		
Minister von Hammerstein			34		
Newton Wonder				34	
Nonpareil (Roxbury Russet)					*51
Nonsuch (Malling Type VI)				34	
Northern Spy				34	
Odlins				34	
Old English Broadleaf				34	
Ontario			34		
Paradise (Malling Stock Type I)				34	
Red Astrachan			34		
Red Siberian Crab			34		
Red Winter Reinette					34
Reinette du Canada	51	38–40	51		
Reinette Zucoamaglio				34	
Ribston Pippin		42	51	51	
Rival				34	
R. I. Greening			51		
Rome			34		
Roter Eiserapfel		47			
Roter Jumpfernapfel			34		
Schoener von Boskop			51		
Sportbluihender *Taffetapfel*			34		
Sommerrambour			34		
Stafner Rosenapfel		48–49			
Stark					*51
Tompkins King			51		
Twenty Ounce			34		
Vaughan Seedless			34		
Wagener					*34
Warner's King		42			
Weidners Goldrenette			34		
Wellington Bloomless			41+1		
Winesap			34		
Winter Banana					34
Winter Magetin				34	
Winter Zitranenapfel		48–49			
Worcester Pearmain				34	
Wolf River					34
Yellow Bellflower			34		
Yellow Newtown			34		

*Unpublished data, used by permission.

1. GENERATIONAL STERILITY

In the first group of factors mentioned by Crane and Lawrence (*loc. cit.*) as a cause of unfruitfulness, pollen sterility, or the production of a large percentage of pollen of low germinability with a high percentage of aborted or shrivelled grains, is very common. Among the varieties that, in our tests, proved to have relatively poor pollen, were Blenheim, Baldwin, Gravenstein and King. It will be noted that all these varieties are triploids, which indicates that triploid varieties should not be depended upon as male parents, as all have given generally inferior results over a period of years. On the other hand, varieties that give relatively large amounts of pollen of good quality, such as Cox Orange, Northern Spy, etc., are diploids. The correlation that exists between pollen viability and chromosome constitution noted by Kobel (1926) is very evident in our tests and strongly supports the view that low pollen germination may be considered as an indication of triploidy. The low pollen germination alone does not account for the low value of triploids as pollinizers. Irregular chromosome behaviour, followed by abortion in the embryos is also a factor. It may be noted that ovule abortion resulting in a low average seed count is another characteristic of triploid varieties.

2. MORPHOLOGICAL STERILITY

Detjen (1926) finds that fruits whose ovules have not been fertilized are generally shed soon after the blooming period, but that the last wave of abscission, *i.e.*, the "July drop" is due mainly to factors which cause embryo abortion. In studies of the Stayman Winesap, Howlett (1931) has shown that an important factor in fruit setting is irregularity in chromosome behaviour during megasporogenesis which would cause *early* dropping. It would appear that most cases of so-called incompatibility are, in reality, cases of embryo abortion due to irregular chromosome distribution.

3. INCOMPATIBILITY

As stated by Crane and Lawrence (1930), among cultivated apples, sterility and incompatibility differ in several respects from the same phenomena in plums and cherries. A salient difference is that incompatibility is rarely, if ever, completely expressed in apples. These workers are writing from a breeding standpoint and with special reference to the production of viable seed, but this fact also applies, to a certain degree, to fruitfulness. A high degree of self-incompatibility has been claimed for many varieties, including Gravenstein, Spy, Cox Orange and Blenheim. With such varieties, even when the pollen is removed from the anthers and matured under ideal conditions, it practically never produces a satisfactory set of fruit in self-pollination tests. At the other extreme is Baldwin, which, though producing pollen of low value for crossing purposes, may yield satisfactory crops when selfed, though not as large crops as when pollinated with pollen from a diploid variety.

Cross-incompatibility has also been claimed for various combinations of apple varieties, though some workers question this. Howlett (1927) in experiments in Ohio, found no evidence of cross-incompatibility and considered apparent cases of this phenomenon to be examples of "cross-sterility, intersexualism, due to impotence of pollen." Einset (1930) tested a number of cases of alleged cross-incompatibility. Only in the case of Arkansas and Grimes was there indication of true cross-incompatibility in the sense employed by East and Manglesdorf (1925), and Crane and Lawrence (1929). The remainder of their tests showed not incompatibility but sterility, which they consider to be due to the effects of zygotic abortion caused by irregularities in the reduction division in the generative cells.

4. PARTHENOCARPY

Several varieties of apples have been reported as showing a tendency to set fruit with few or no seeds. Gravenstein is the most important of our local varieties to show this tendency. Ribston Pippin, not studied by us, is another. Among other reported varieties are Antonovka, Alexander, Crimson Bramley and Longfield. Kobel (1930 & 1931) noted the tendency of varieties with low pollen germination and irregular chromosome distribution to set few or no seeds. He designates as "false parthenocarpy," those cases in which fertilization has actually taken place, but, owing to the irregular chromosome distribution, seed development does not take place. Even in Gravenstein, which shows the greatest tendency to produce seedless or few seeded fruit, there is strong evidence that seed formation is a decided advantage in fruit setting, and Einset (1930) has even found a correlation between seed content and weight, though such a correlation was not obtained by us.

Extensive counts from various standard varieties always reveal a higher average seed count in apples that remain on the tree than in those that come off in the July drop. Individual fruits may vary, but the foregoing was true for averages. Numerous workers have held that such production is so intimately associated with the physiological processes of the fruit, that apples with developed seeds have an advantage in the competition for water and organic nutrients over those that have fewer or no seeds and this is confirmed by our results. It is, however, true that triploid varieties are able to set fruit with a lower content of developed seed than in the case in diploids. Data with respect to the relation between fruitfulness and the production of seeds and seedlings are presented later.

In connection with the production of seedlings resulting from various crosses, the difference between diploids and triploids is very pronounced, the latter, as a group, giving a very low percentage of seedlings. The number of seeds and seedlings resulting from different crosses on any given female parent should therefore, be a useful index of the value of the male parent as a pollinizer for that variety. But within the triploid group those crosses that give the larger number of seed are more fruitful than those that yield a smaller number, though the average number of seed for the group is much less than in diploids. Data bearing on this point are presented in another section.

D. PERCENTAGE OF FRUIT TO FLOWERS REQUIRED TO GIVE AN ECONOMIC YIELD

This problem is discussed only from the standpoint of commercial orchards in the Annapolis valley. As previously noted the per cent of blossoms, which, in the apple, is required to develop into mature fruit is small compared with stone fruits. The percentage that actually sets fruit varies with different factors already discussed, according to the amount of bloom present on the tree, and with the variety. With a small bloom, as many as fifteen, twenty or even a higher percentage may be obtained; but, with a full bloom, five per cent is the figure ordinarily given as representing a satisfactory commercial set. This is a convenient, though arbitrary figure, since, of course, varieties differ in regard to the number of apples necessary to produce a crop that can be called commercial. A number of workers (*vide* MacDaniels, 1930) stress the advisability of taking into consideration the number of fruiting centres. Howlett (1929), for example, finds that in Stayman Winesap one apple to every third flowering spur is sufficient for a commercial crop. Lattimer (1931) contends that more attention should be given to expressing fruit-set on the basis of spurs rather than individual flowers, pointing out that if more than one fruit per spur sets it should be thinned. The foregoing is undoubtedly true and, under orchard conditions, it is often advisable to thin a tree that is bearing less than a normal crop, because of clustering on a portion of the spurs.

Nevertheless, where natural pollination occurs there is no way of avoiding uneven setting.

Some varieties are poor female parents, *i.e.*, they shed a higher proportion of blossom and fruit than others, having a tendency to thin down to one fruit to the spur; others have a tendency to set in clusters. The fruiting habits of a number of standard varieties are shown in the accompanying table, in which the year **1929** is taken as the basis for comparison with the three-year average for **1928-1930** inclusive. In this year all trees blossomed heavily and the set was unusually good.

TABLE No. 4.—*BLOSSOMING AND FRUITING HABITS OF FOUR STANDARD VARIETIES*
(Average of 16 Orchards)

Variety	Per cent fruit (1929)	Crop per tree 1929 (bbls.)	Average crop in bbls. (1928-30)	Average number apples per tree (1929)	Average number apples per bbl. (1929)	Calculated number blossoms per tree (1929)
Gravenstein	5·68	2·67	3·00	1,291	430	22,720
King	4·49	4·10	3·02	1,640	543	36,525
Baldwin	11·32	3·73	5·01	2,051	681	18,122
Spy	9·13	4·11	4·26	2,053	482	22,508

From these figures it will be seen that though the King trees included in this survey have a larger average number of blossoms than the other varieties, the percentage of fruit is lower. Nevertheless, since the King apples are large, the final number of barrels produced is short only of the Spies. In the case of Baldwin, which has a decided tendency to set in clusters, the percentage set is heaviest, but, since the number of blossoms per tree is the smallest and the fruit size is also the smallest, the total crop in barrels is less than that of King or Spy. The heavier set obtained with this variety may be a factor in its biennial bearing habit in so many orchards.

Comparing the foregoing figures with the average result of hand pollinations carried out for the three-year period **1928-1930**, we find that Baldwin has given an average per cent fruit of **11·07**; Cox Orange, **7·64**; Golden Russet, **4·40**; Gravenstein, **6·16**; King, **4·0**; Spy, **7·63**. The massed results showing average figures for the four varieties from 16 commercial orchards may be of some interest in this connection and are given for comparison.

TABLE No. 5.—FRUITING HABITS OF FOUR STANDARD VARIETIES, AVERAGE OF FOUR FOR *1928-1930*

Orchard	Total blooming spurs counted	Average per cent with bloom	Average blossoms per blooming spur	Average per cent fruit
A	3,546	55·50	5·08	11·44
B	2,870	44·25	5·07	9·79
C	3,439	44·74	5·17	6·23
CA	2,031	34·51	5·39	7·26
D	3,089	44·69	4·90	2·07
E	2,094	62·03	4·83	8·61
F	3,096	42·97	4·75	6·64
G	2,861	54·13	4·63	6·46
H	2,619	47·32	4·91	7·31
I	2,851	60·69	4·70	5·76
K	2,541	73·16	4·85	6·49
L	2,558	59·39	5·02	10·59
M	3,344	55·81	4·64	8·74
N	3,252	54·68	4·89	7·19
O	3,009	51·88	4·70	8·47
P	3,329	49·48	4·56	

III. EXPERIMENTAL STUDIES IN APPLE POLLINATION

W. H. BRITTAIN and DONALD S. BLAIR

A. CONDITIONS FOR CROSS-POLLINATION

In considering the pollination question for commercial orchards two questions must be kept in mind, viz., (1) the necessity of an abundant supply of effective pollinizers for each variety planted in the orchard and (2) the presence of an adequate force of pollinating insects to insure that cross-pollination is effected.

The conditions that may be found within a commercial planting are as follows:—

1. The orchard may be planted with a suitable mixture of cross-fruitful varieties.

2. The orchard may be set out with cross-unfruitful varieties, *e.g.*, Gravenstein, Blenheim and Stark planted together.

3. Varieties may be planted together in such a way that one variety is not supplied with an effective pollinizer, *e.g.*, Cox Orange planted with Blenheim. In this case Cox Orange is a suitable pollinizer for Blenheim, but the Blenheim (an ineffective pollinizer) is incapable of cross-pollinating the self-unfruitful Cox Orange.

4. Self-unfruitful varieties may be planted in such large blocks that cross-pollination is impossible.

5. For any one of the above conditions an effective population of pollinators may be lacking, which would be a limiting factor in each case.

B. PREVIOUS WORK WITH BEES AS POLLINATORS UNDER CONTROLLED CONDITIONS

Several workers have tested the value of bees in experiments in which hives are introduced beneath tents covering the trees. In some of these cases the necessity for cross-pollination is apparently ignored as no source of compatible pollen was supplied, resulting in selfing and a low set of fruit, as might be expected. Morris (1921) found no advantage from having Jonathan and Rome Beauty trees selfed by bees. Macoun (1923) found that McIntosh set a satisfactory crop when supplied with bees and a source of compatible pollen or when wild bees were allowed access to the flowers under the same conditions, but a very low yield was obtained when all bees were excluded. Hutson (1926) tented two trees each of Wealthy and Jonathan, one each with bees and one without. The Wealthy gave a set of 17 per cent with bees and 4·02 per cent without; the Jonathan gave 8·4 per cent with bees and ·80 without. Many workers have noted that caged trees or bagged limbs from which bees are excluded yield little or no fruit and much similar information is available from experiments in inter-fruitfulness of varieties carried out under tents, to which reference is made elsewhere.

C. EXPERIMENTS IN BEES AND POLLINATION

(Tent Studies)

1. OUTLINE OF EXPERIMENTS

In order to determine the effect of the different treatments outlined under the heading "Conditions for Cross-pollination," there was initiated in 1929 a series of experiments in which bearing trees of four standard varieties were enclosed in tents and subjected to conditions in simulation of those referred to in the foregoing. The trees then were seventeen years old, in excellent condition, and grown under similar conditions of culture. All these experiments were carried on at the Experimental Station orchard at Kentville.

The following were the treatments accorded to the trees in the different tents:

(a) Supplied with pollinizing bouquets of an effective pollinizer and with a colony of bees, thus furnishing the tree both with a proper pollen supply and with insect pollinators.

(b) Supplied with pollinizing bouquets of an ineffective pollinizer and with a colony of bees, thus furnishing the tree with adequate provision for cross-pollination, but with a supply of unsuitable pollen.

(c) Supplied with a colony of bees, but with no pollinizing bouquets of any kind, thus ensuring that the tree would be self-pollinated by the bees.

(d) Supplied with neither bees nor bouquets of any kind, thus preventing pollination except such self-pollination as would occur through the agency of wind or gravity.

(e) Supplied with bouquets of an effective pollinizer but with no bees. This test was started in 1930. This tree, therefore, while having a supply of suitable pollen provided, was deprived of the normal agency of cross-pollination, except in so far as wind may be effective in this regard. In 1931 and 1932 a current of air from an orchard duster was blown very thoroughly through the bouquets and over the trees. It was only in 1932 that there was any evidence that any appreciable pollination was achieved by this method. This is accounted for by improvement in technique in the latter year. About half an hour was taken at each tree and the air current directed through the bouquet in all directions. It is highly improbable, however, that ordinary wind could produce the same effect as a current of air produced in the foregoing manner.

(f) The results from the foregoing trees were compared with records from neighbouring untented trees grown under similar conditions. Since the orchard was well laid out from the standpoint of the intermixture of cross-fruitful varieties and, since colonies of bees were placed throughout the orchard, this series was provided both with an adequate supply of suitable pollen and with insect pollinators sufficient to ensure cross-pollination. In 1931, owing to a certain amount of poisoning among the bees and probably other factors, the bee population was lower than in other seasons.

As a further check on the foregoing experiments three limbs of as nearly as possible uniform size and condition were selected in each tent and treated as follows:

1. On trees with bees and bouquets, (i.e. on trees (a) and (b)):

(i) *Enclosed one limb with a cheesecloth bag and allowed it to remain untouched.*

(ii) *Bagged one limb and self-pollinated the blossoms.*

(iii) *Bagged one limb and pollinated blossoms, with the same variety of pollen used in the bouquets—an effective pollinizer in (a) treatment and an ineffective pollinizer in (b) treatment.*

FIG. 3.—Section of Kentville Experimental Station orchard showing tented trees (original).

2. On trees with no bouquets (*i.e.* (*c*) and (*d*) and trees with no bees (*i.e.* (*e*)) and on the untented tree (*i.e.* (*f*)):

(i) *Bagged one limb and left it untouched.*
(ii) *Bagged one limb and self-pollinated blossoms.*
(iii) *Bagged one limb and pollinated the blossoms with pollen from a cross-fruitful variety.*

Thus, in each case we have for comparison individual hand pollinated or untouched limbs to check against the results from pollination with bees, or with blossoms unpollinated except by wind.

The varieties chosen for these tests were Gravenstein, King, Baldwin, and Spy, a range covering the blossoming season. Included are two varieties which may be numbered among the most self-unfruitful of commercial sorts, viz., Gravenstein and Spy. The former is a triploid form having a tendency to produce a certain number of seedless or few-seeded fruits, especially under some conditions. Intermediate in position is the King, which, in some seasons, has appeared as self-unfruitful as any variety, but in others has given a fair set when selfed, though never as large a set as when crossed with a cross-fruitful variety. Baldwin is a striking exception in that it is uniformly self-fruitful to a larger extent than any variety tested. This variety, though a triploid form, with pollen of low germinability and possessing a high proportion of aborted grains, very inferior for crossing, is yet highly self-compatible. Gravenstein, though varying considerably from year to year is markedly inferior for crossing purposes to such varieties as Cox Orange, Wagener, Golden Russet, etc., which, with Northern Spy, are among the most effective pollinizers among commercial sorts grown in the Annapolis valley.

For pollinizing bouquets, limbs of the desired varieties well covered with bloom were removed and placed in large cans of water. The first year, only a single bouquet was used per tent, but it was found that the set on the side next the bouquet was much greater than that on the opposite side. Therefore, in following years two bouquets, one on each side of the tree, were employed. In the very hot blossoming season of 1930 there was a decided tendency to wilt on the part of the bouquets, which made them less attractive to the bees and had an adverse effect on setting. This was avoided in 1931 by frequent changing of the bouquets whenever it became necessary.

For ineffective pollinizers Blenheim was generally used for Gravenstein and King. For Baldwin and Spy, Nonpareil was employed. As effective pollinizers we used Wagener for Gravenstein, Wagener or Golden Russet for King, Cox Orange for Baldwin and the same variety or Ben Davis for Spy.

Package colonies of bees were used as pollinators and in 1928-1931 proved quite satisfactory. In 1932 overwintered colonies were used.

The results of tent experiments have been discounted by certain workers on account of the supposedly "unnatural conditions" but we were unable to secure any evidence to indicate that our results were affected by artificial conditions inside the tent. Hygrograph and thermograph charts herein presented show a remarkably slight variation between inside and outside conditions.

2. GENERAL RESULTS OF TENT EXPERIMENTS

The accompanying table summarizes the results obtained from this series. These results bring out clearly the necessity of proper attention being given to the right admixture of varieties in orchard plantings and equally the importance of the presence of pollinating insects in order to obtain a commercial crop.

All varieties respond by increased sets of fruit to the application of the pollen by cross-fruitful varieties to their stigmas and all but Baldwin give

decidedly inferior results when selfed. This is less true of King than the other varieties tested, which, from the standpoint of per cent fruit obtained, may be considered a poor female parent, and shows less difference than other varieties between effective and ineffective male parents. The abundant bloom of this variety, coupled with the large size of the fruit and its annual bearing habits compensates, in a measure, for the low percentage fruit obtained with all crosses, so that King may be regarded as a commercially fruitful variety.

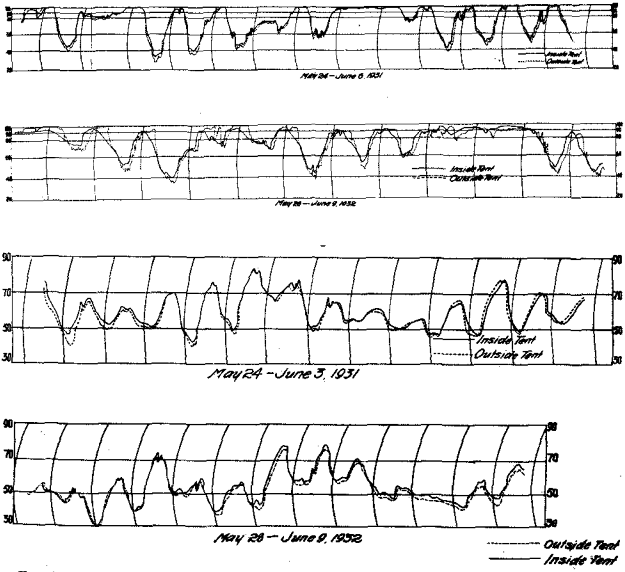

FIG. 4.—Humidity and temperature records inside and outside tents, Kentville, N.S. (1) May 24-June 6, 1931; (2) May 24-June 3, 1931; (3) May 28-June 9, 1932; (4) May 28-June 9, 1932 (original).

The average seed per fruit for each treatment in tent series was taken in 1932. This figure proved to be a very reliable index as to fruitfulness. For each variety tested, either diploid or triploid, the seed content per apple increased proportionally to the pollination provided, *i.e.*, the more perfect the conditions for pollination the greater the number of seeds per fruit. The 1932 tented figures are in agreement with those obtained in the standard varieties, during the period 1928-1932.

In order to avoid repetition a discussion of the detailed results of these experiments is included in the next section.

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TABLE No. 6.—SUMMARY OF TENT STUDIES (1929–1932)

Variety Tree Treatment	Results of treatment			Unpollinated			Selfed			Effectively pollinated			Ineffectively pollinated			Average seeds *per* apple, 1932
	No. blossoms	Per cent set	Per cent fruit	No. blossoms	Per cent set	Per cent fruit	No. blossoms	Per cent set	Per cent fruit	No. blossoms	Per cent set	Per cent fruit	No. blossoms	Per cent set	Per cent fruit	
Gravenstein—																
Bees and effective bouquets	10,814	21·18	10·90	1,000	0·80	0·50	811	0·86	0·37	816	34·80	18·38				4·73
Bees and ineffective bouquets	10,562	1·71	1·14	905	0·00	0·00	661	1·21	0·61				595	4·37	2·18	1·27
Bees and no bouquets	11,768	3·05	2·12	792	1·14	0·51	606	1·65	0·50	773	29·88	22·25				1·46
No bees and no bouquets	10,313	0·90	0·67	757	0·66	0·40	434	0·46	0·23	484	70·66	47·11				1·14
No bees and effective bouquets[1]	4,912	0·69	0·47	361	0·00	0·00	342	0·29	0·29	398	37·44	33·67				2·30*
Open pollinated	12,396	21·62	9·91	1,254	2·07	0·88	1,005	1·59	1·39	892	43·05	11·21				3·49
King—																
Bees and effective bouquets	10,347	30·11	5·42	869	4·49	0·35	631	16·80	1·74	683	29·28	7·32				6·39
Bees and ineffective bouquets	10,228	21·05	3·58	559	14·31	1·43	439	20·27	2·73				488	21·52	5·12	2·52
Bees and no bouquets	10,265	15·54	3·32	526	3·61	0·38	548	12·96	2·55	457	37·20	11·60				3·10
No bees and no bouquets	9,749	4·13	1·03	549	4·19	0·55	529	17·96	3·40	699	37·63	11·87				2·29
No bees and effective bouquets[1]	4,808	9·65	1·81	303	4·95	0·66	278	24·10	8·27	286	38·81	12·59				3·23*
Open pollinated	10,782	15·42	4·74	984	6·30	1·63	692	14·31	1·88	606	31·02	8·25				5·33
Baldwin—																
Bees and effective bouquets	10,496	31·11	8·17	1,037	8·29	1·64	754	17·51	2·65	654	45·41	12·69				5·92
Bees and ineffective bouquets[2]	6,902	26·53	4·96	644	16·46	2·02	581	16·52	4·82				491	24·64	5·91	2·53
Bees and no bouquets[2]	7,422	25·36	7·77	690	12·61	1·01	586	12·97	2·22	455	30·33	8·13				2·63
No bees and no bouquets	9,946	8·23	3·49	653	9·80	3·06	454	16·30	5·07	590	43·05	19·15				1·15
No bees and effective bouquets[1]	4,715	9·67	5·05	360	8·61	3·89	448	29·46	9·60	330	39·39	18·79				3·04*
Open pollinated	9,881	30·23	10·40	1,000	11·20	3·70	730	17·67	4·11	707	48·51	19·24				5·26
Spy—																
Bees and effective bouquets	7,489	49·21	10·05	739	0·81	0·00	685	1·17	0·73	473	83·09	18·18				13·37
Bees and ineffective bouquets	10,313	3·64	2·70	890	0·22	0·22	769	2·73	0·78				743	11·04	5·92	1·70
Bees and no bouquets	10,006	2·46	2·00	799	0·13	0·13	818	1·10	0·73	821	62·00	22·66				2·22
No bees and no bouquets	10,393	1·09	0·85	1,004	0·10	0·10	546	3·30	3·11	577	66·90	26·34				
No bees and effective bouquets[1]	6,066	1·83	1·20	289	1·04	1·04	345	3·19	2·61	372	60·22	19·35				4·76*
Open pollinated	9,987	20·77	8·83	1,302	3·09	0·46	583	3·09	0·69	709	43·86	16·22				8·81

[1]Two years' results only.
[2]Three years' results only.
*Pollinated by forced draught currents from orchard duster in 1932.

D. STUDIES IN THE INTER-FRUITFULNESS OF STANDARD VARIETIES

1. OBJECT OF EXPERIMENTS

The fact has been brought out in the preceding experiments that all varieties benefit by cross-pollination. Furthermore, it is clear that it is not sufficient merely to plant together varieties that blossom at the same time, since some varieties give poor results when used to pollinate others. Some that are good pollinizers for other varieties are themselves highly self-unfruitful and some, that yield good results when pollinated with pollen from a suitable variety, are themselves deficient as pollinizers. A study of the results obtained in hand-pollination tests gives useful information as to the inter-fruitfulness of the varieties tested and also makes clear certain general principles applicable to all work of this kind.

The varieties chosen for these standard tests were as follows:—

Gravenstein	Baldwin
King	Cox Orange
Golden Russet	Northern Spy

Certain other varieties were used as pollinizers as opportunity offered. McIntosh might well have been added to the list, but so much information is available regarding this variety from other sources that it was not considered necessary. Special tests with the varieties Blenheim and Stark are described in another section.

2. TECHNIQUE OF PROCEDURE AND DEFINITIONS OF TERMS USED

Vigorous trees of the same age and growing under similar cultural conditions at the Experimental Station, Kentville, were selected. In a few cases, where the desired variety did not happen to be available through lack of sufficient bloom, resort to other orchards was made, since in all cases, only trees in good bloom were used.

During the first year of our work as many crosses as possible were placed on a single limb, in order to give each cross an even chance with others. In 1929,

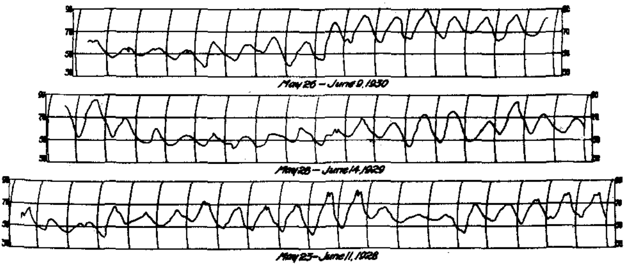

FIG. 5.—*Thermograph records during blooming period, 1928-30, Kentville, N.S. (original).*

however, six trees of each variety were selected and in 1930-1932, ten trees. A different limb was selected on each, for each cross that it was desired to make. In order to reduce to a minimum any error resulting from differences in limbs from different sides of the tree a rotation of the different hand pollinated limbs was practised. This method was carried out throughout the experiment.

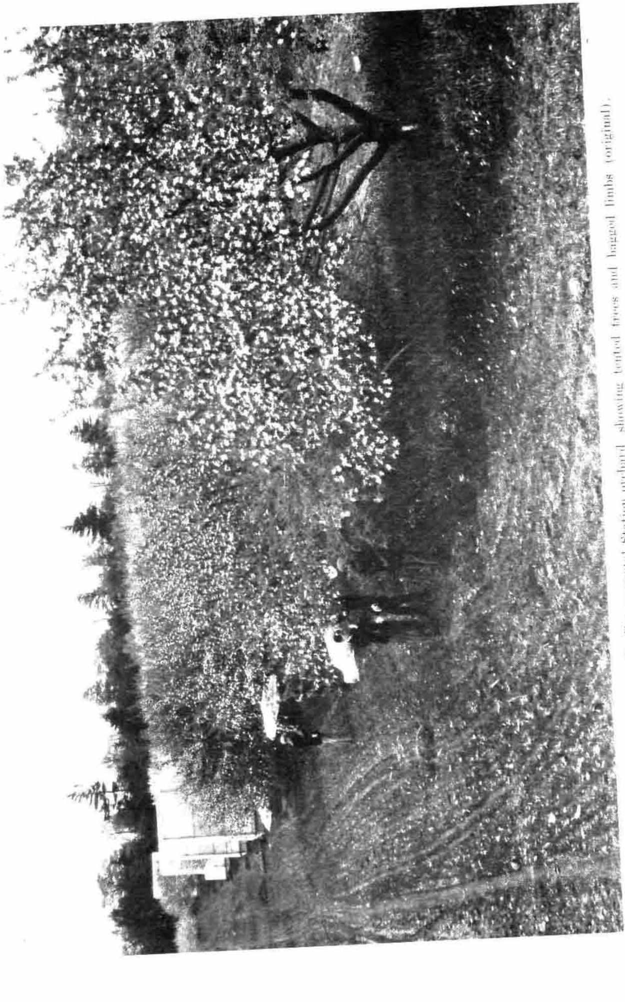

Fig. 6. Section of Kentville Experimental Station orchard showing tented trees and bagged limbs (original).

Owing to nutritional variation between trees and even between limbs on the same tree, a certain number of laterals in all limbs used in the crossing work were selected to be self-pollinated, to establish a uniform basis for comparison and to reduce error to a minimum. Owing to the fact that this method tended to complicate record taking this practice was discontinued in 1932 and individual limbs were also used for selfing tests.

During the first year paper bags were used, but it was found much more convenient and equally effective to use cheese cloth bags covering the entire limb. The large sets obtained from suitable crosses under these conditions do not indicate that the normal process of pollination and fertilization was interfered with by this treatment.

When the majority of stigmas for any variety were receptive they were brushed with the appropriate pollen, applied by means of a camel's hair brush, all blossoms that had not reached or had passed the receptive stage being removed. After the stigmas commenced to wither the bags were taken off.

In these studies emasculation was neglected in order to eliminate work and *to make it possible to perform a very large number of pollinations*. A word of explanation will make clear the reason for this practice. The object of these investigations was not to secure seed from various crosses for breeding work, but to test the value of the pollen of one variety as a means of improving the *set of the variety considered as a female parent*. As tests of self-fruitfulness were conducted in the manner already described, the per cent of self-fruitfulness obtained may be compared with the result of each cross on each limb. While emasculation might provide better control, as far as contamination from its own pollen is concerned, it reduces the number of pollinations possible and provides a further source of error due to emasculation injury.

The low, and, in many cases, almost negligible set obtained from most self-pollinations under bags, further reduces the chances of error and, when it is considered that all pollinations were made with previously prepared pollen applied to the stigma of the flower as far as possible before their own anthers had dehisced, it will be seen that this source of error is greatly reduced. Furthermore, a study of the characteristics of seedlings obtained from the seed saved from the various crosses, indicates that selfing could not have taken place to such an extent as to prevent the results of these tests from being very significant. In the case of Baldwin considerable selfing undoubtedly occurred, this variety showing a high degree of self-fruitfulness in all years, but, this fact being clearly recognized, it does not affect the nature of the results from a pollination standpoint.

Our conclusions with respect to the different crosses are based upon a consideration of (1) the count of fruit as obtained after the unfertilized blossoms have been shed, and (2) the percentage fruit that remains after the "July drop" and (3) upon the fruit obtained at picking time. The term "set," as used in this report, applies to the first of these, i.e. the count made before the "July drop." *This, by some workers, is considered the best criterion of the value of* different crosses, as they consider that nutritional factors play a large part in the later drop. The term "per cent fruit," as used in this report, refers to the percentage fruit that remains after the "July drop."

After a careful study of all relevant data it would appear that this figure affords the best index of cross-fruitfulness or unfruitfulness. In the case of some varieties there is little difference between the "per cent set" and "per cent fruit." Gravenstein may be cited as an example of such a variety. In other cases the original set for all male parents may be much the same, but, after the "July drop," a wide difference becomes apparent between diploid and triploid male parents. An example of the foregoing is Stark. The percentage that remains on the tree at picking time is usually little different, except for abnormal

conditions, or for purely accidental causes, as high winds, which, when they occur, considerably reduce the value of this figure. Another point that has been considered in weighing the value of various crosses is the question of seed production. The term "per cent seed" refers to the seed produced from the original number of blossoms pollinated and the term "per cent seedlings" refers to seedlings produced from the original number of blossoms pollinated. The average number of seed per fruit was also found to be significant.

In these experiments we have not recorded the number of fruits borne on a spur. While it might doubtless be advantageous to take into account the number of fruiting centres in expressing results, the large number of pollinations made, the fact that only normally blossoming limbs were selected, and the length of time over which the work has been carried out, are considered to have evened out spur differences and to give a valuable figure on which to base comparisons.

Two practices are commonly followed in expressing results of pollination studies. One is to use only the per cent fruit obtained from the original number of blossoms pollinated, the other (2) is to express results as "percentage of a commercial crop." It is pointed out by those who follow the latter practice that to express results only in terms of blossoms that set fruit is to ignore important factors which influence the set of fruit, particularly in view of the fact that a percentage of fruit that might be ample with a heavy bloom, would be very inadequate when the bloom was light. Furthermore, the same percentage may be obtained in cases in which widely varying distribution of the fruit on the limbs may be obtained. Whatever method is followed is arbitrary and it seems to be just as difficult to lay down a definite rule as to what consitutes a commercial crop, as to interpret results on the basis of percentage fruit obtained, which, at least, forms a basis of comparison between varieties. In our work, therefore, we have chosen to use the figure showing the percentage blossoms that develop into fruit. Taking into account the normal bearing habits of the different varieties concerned and bearing in mind the fact that the practice followed was to select for pollination only limbs in good bloom, it is considered that this method meets the needs of the case and renders intelligent comparisons possible. The figure of five per cent, selected by some workers as representing a commercial set, is a useful one, though, as indicated elsewhere, the bearing habits of varieties differ and the proportion of blossoming spurs would have an important influence.

3. POLLEN TESTS

(a) METHOD

In order to keep a careful check upon the results of hand pollinations, all pollen used in the work was tested for germination. Blossoms were gathered from trees of the required varieties before fully opened, the stamens stripped of their anthers by means of forceps, and dried in the sun or on the top of an electric oven running at 50°C. Ordinarily the pollen was stored in small open petrie dishes in desiccators or in a large chamber used as a desiccator. Wherever possible mixed samples from the different trees were secured, to eliminate error due to differences in vigour in the pollen tree.

Each petrie dish was labelled with the name of the variety of pollen, and the date gathered. Vials for use in the orchard were correspondingly labelled. As the pollinators went out each morning the pollen was transferred from the petrie dish to the vial with duplicate label.

The daily germination tests were run as follows: The medium 15 per cent cane sugar solution with ·5 per cent agar added, was sterilized and run into a number of test tubes, which were kept plugged, a fresh one being used for each day's tests, thus eliminating all possibility of contamination of the medium.

Three slides were put up with each variety of pollen, the pollen being stirred with a needle into the agar on a cover slip, which was then inverted over the cavity of a well slide, the edge of the well being coated with vaseline to make it airtight. After 24 hours germination at room temperature the cover slips were transferred to ordinary slides on each of which was a drop of 5 per cent lactic acid. The acid acted as a killing agent, enabling each slide to be kept for several days and read at leisure.

Three fields containing 100-150 grains were read on each slide giving a total of approximately 1,000 grains for each variety. At the beginning of the investigation tests were run on various germinative media, but finally 15 per cent sugar agar was selected as being most satisfactory. The tests were run at approximately 68°F.

(*b*) RESULTS

The accompanying tables indicate the results by years and show the actual per cent germination obtained from the pollen samples used in our studies.

TABLE No. 7—GERMINATION OF APPLE POLLEN (1928–1932)

Variety	1928	1929	1930	1931	1932
Annie Elizabeth (d)			(3) 53·75		
Baldwin (t)		(4) 0·22	(3) 21·00	(3) 56·60	(3) 10·67 (4) 2·04 (5) 3·67 (1) 25·04 (5) 2·31 (3) 13·00
Ben Davis (d)			(2) 45·27	(2) 85·18	(3) 53·95 (4) 72·40
Bishop Pippin (Yellow Bellflower) (d)		(4) 68·00	(2) 52·64	(2) 87·50	
Blenheim (t)	7·00	(3) 5·60	(2) 21·75	(2) 52·20	(4) 15·07 (5) 2·66 (8) 16·70 (5) 20·00
Chas. Ross		(2) 76·00	(3) 44·44		
Cox Orange (d)	29·50	(3) 38·90	(2) 53·42	(2) 47·61	(3) 23·53 (4) 54·25 (5) 52·46 (3) 56·29
Crimson Beauty (t)			(1) 37·11	(5) 24·77	
Crimson Bramley (t)		(3) 30·00	(3) 15·00		
Delicious (d)		(3) 27·24	(1) 60·00	(2) 92·50	
Duchess (d)		(3) 57·91	(2) 48·05	(3) 88·75	
Emilie		(2) 80·83			
Fallawater			(2) 10·00	(2) 31·00	
Fameuse (d)			(2) 61·51	(2) 46·75	
Golden Russet (d)		([illegible]) 25·51	(11) 38·40	(1) 85·50	(7) 33·78 (4) 46·10 (6) 25·38 (7) 35·69 (5) 47·44 (3) 44·29
Gravenstein (t)	2·00	(3) 14·76	(2) 10·55	(2) 46·75	(4) 27·41 (5) 24·00 (4) 13·65 (7) 17·21 (1) 21·63 (2) 18·56
Grimes Golden (d)		(3) 76·25	(4) 33·94	(2) 80·12	
Hubbardston				(2) 92·03	
Jonathan (d)		(3) 36·22	(2) 49·73	(2) 93·00	
King (t)	15·00	(3) 1·66	(14) 3·00	(2) 27·67	(5) 15·57 (5) 9·33 (7) 1·20 (3) 11·06
Kinkead		(3) 70·83	(3) 70·62		
Lane's Prince Albert			(3) 33·33		
Lipton			(4) 74·40		
Lobo		(2) 70·67	(3) 58·27		
Longley Pippin			(3) 51·00		

TABLE No. 7—GERMINATION OF APPLE POLLEN (1928–1932)—*Conc.*

Variety	1928	1929	1930	1931	1932
Melba		(2) 38·67	(3) 77·65	(2) 83·97	
Maiden's Blush			(4) 66·00		
Mam. Blacktwig		(3) 14·67	(3) 32·11		
McIntosh	12·00	(4) 35·15	(2) 53·33	(2) 48·00	(4) 58·03 (1) 57·05 (2) 48·34
Milwaukee			(2) 40·20		
Nonpareil (Roxbury Russet) (t)		(3) 15·44	(2) 29·20	(4) 20·13	(3) 38·59
Opalescent			(10) 36·25		
Ontario (d)				(3) 70·00	
Ortley			(3) 50·00		
Red Astrachan		(2) 89·86	(1) 48·36	(2) 61·25	
R. R. Beauty			(4) 55·80		
R. W. Reinette			(10) 30·07		
R. I. Greening (t)		(4) 15·76	(2) 0·00	(2) 36·66	(3) 21·62
Rome Beauty		(3) 69·27	(4) 40·53		
Ribston (t)		(3) 0·59	(2) 19·62	(3) 57·00	
Salome		(2) 74·39	(3) 64·82		
Stark (t)			(3) 14·00	(3) 25·22	(5) 19·23 (8) 18·31 (5) 23·32
Spy (d)		(3) 24·00	(1) 39·11	(1) 86·89	(3) 54·76 (4) 68·35
Seek-no-Further		(3) 72·26			
Stayman Winesap			(3) 68·40	(2) 26·22	
St. Lawrence		(3) 52·11			
Wagener (d)	41·00	(3) 69·41	(2) 42·70	(2) 62·20	(4) 48·04 (5) 73·28 (3) 58·43 (4) 60·56 (5) 63·13 (2) 53·37
Wellington (d)				(3) 77·55	
Winter Banana		(3) 74·34	(3) 90·00	(2) 87·00	
Wolf River (d)		(3) 57·00	(1) 48·66	(2) 57·77	
Worcester Pearmain (d)		(2) 71·83	(7) 33·53		
Yellow Transparent		(3) 100·00		(2) 89·11	
York Imperial		(3) 95·00		(2) 92·50	

Note (1)—In 1928–1929, 10% sugar was the medium used.
" 1930–32, 15% sugar-agar was employed.
Note (2)—Figures in brackets indicate age of pollen in days.
Note (3)—t = triploid; (d) = diploid.

Considerable error is to be expected in germination tests in spite of every possible precaution and the making of much larger counts than usually considered necessary. Neither should it be supposed that germination tests made under artificial conditions are exactly indicative of the fertilization capacity of pollen, for many other factors are involved. It will be noted, however, that some varieties show a uniformly higher germination than others. Although no direct correlation between germination and set has been arrived at, it is generally observed that a pollen with high germination will give a better set than a pollen with low germination; sometimes higher than would be expected, sometimes lower. Those with a generally low percentage germination and a high percentage of aborted and shrivelled grains include Blenheim, Crimson Bramley, Baldwin, R. I. Greening, Gravenstein, Bramley, King and Ribston which are triploids, to which might be added Nonpareil and Stark, and several others which, judging from their behaviour in this and other respects will probably be found to be triploids; while of the known diploids, Spy, Delicious, Ben Davis, Jonathan, Yellow Transparent, Ontario, Red Astrachan and others have a relatively higher germination and a lower proportion of aborted grains.

In this connection, Einset (1930) states: "In view of the cytological evidence, it seems apparent that the low pollen germination is not directly responsible for the ineffectiveness of the triploid varieties, Gravenstein and

Baldwin, as pollinizers. Even though the percentage of viable pollen is low, there should remain a sufficient supply in many cases to insure fertilization and subsequent seed development. It seems obvious, however, that the irregular chromosome distribution, which has supposedly cut down the percentage of

FIG. 7.—Germinating pollen from certain apple varieties: (1) pollen of Baldwin; (2) King; (3) Wagener; (4) Golden Russet; (5) Spy; (6) Gravenstein (original).

viable pollen, is now causing further abortion in the zygotes." This agrees with the observations of Kobel (1930 and 1931) that a high pollen germination is characteristic of diploid varieties and a low germination of triploid varieties. The results of all our tests are in agreement with the foregoing conclusions.

An interesting feature brought out by our tables is the variability of the results of germination tests. There is undoubtedly a large factor of error in this work, but it is apparent that in diploid varieties the pollen is generally good, in triploids generally poor. Furthermore, in some seasons the germination is proportionally better than in other seasons. As already indicated the pollen tests carried out in connection with the foregoing studies were undertaken solely as a check on the germination of the samples used and, as such, appear to be reasonably adequate. Heilborn (1932) rightly points out that most germination percentages are based on too few counts. He further contends that a proper comparison between the pollen of different varieties cannot be based upon percentage figures of germination, determined without due regard to the amount of empty pollen grains characteristic of each variety and without a very strict control of the conditions prevailing during germination experiments. He considers that percentage germination figures bring out one thing only, viz., the profound difference between diploid and triploid sorts. He contends that all differences in pollen morphology are not due to chromosome aberation and that triploid and diploid varieties must be treated separately. In evaluating diploid varieties he considers it essential to use viability figures *i.e. germinability* instead of germination percentage. He divides diploid varieties into three categories on this basis and concludes that in such varieties there is a sharp distinction between wholly fertile and partially sterile varieties, of which only the first mentioned should be regarded as perfect pollen producers. He presents evidence to show that the sterility has a genetical basis and is, to a high degree at least, independent of climatic or metabolic conditions, being caused by lethal gene combinations.

(i) *Other Data.*—Experiments to determine the optimum temperature for pollen germination under artificial conditions, showed considerable apparent difference between varieties, the point varying between 17.8° C. and 25.6° C. Germination occurred from all temperatures above freezing to about 57° C., but

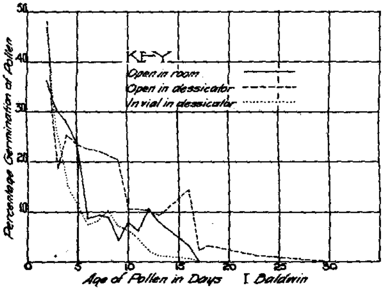

FIG. 8.—Influence of age on germinability of Baldwin pollen under different conditions of storage (original).

at the lower temperatures pollen-tube growth was very slow, finally, however, attaining the length characteristic of the variety. Pollen retains its viability best when stored in open petrie dishes in desiccators, especially in damp weather. Under these conditions good germination is obtained for several days. Northern Spy showed greatest longevity under the conditions of the test, germinating up to 29 per cent when 10 days old, 3.06 per cent at 23 days, but no germination at 30 days. Germination at 3 days was 70 per cent. Where stigmas of apple

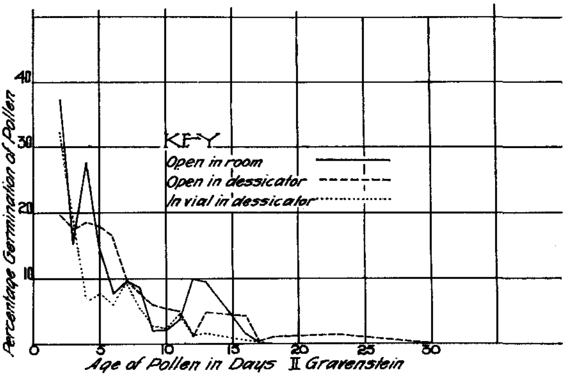

FIG. 9.—Influence of age on germinability of Gravenstein pollen under different conditions of storage (original).

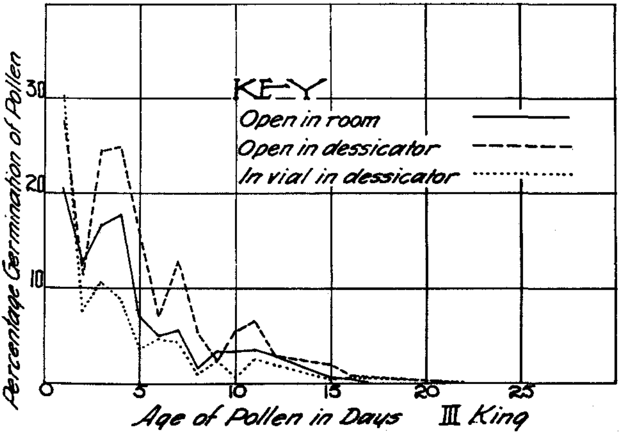

FIG. 10.—Influence of age on germinability of King pollen under different conditions of storage (original).

varieties were introduced into the germinative media there was no evidence of any effect on germination. Where foreign stigmas were introduced some of them produced a lethal effect.

In experiments in carriage of pollen by wind, glass slides were smeared with liquid petrolatum and placed in spore traps of the weather vane type at the edge of the orchards at varying distances from the trees. Apple pollen was found on all the slides up to 200 ft., the counts running as follows: 25 ft., 325 grains; 50 ft., 267 grains; 75 ft., 169 grains; 100 ft., 80 grains; 150 ft., 46 grains; and 200

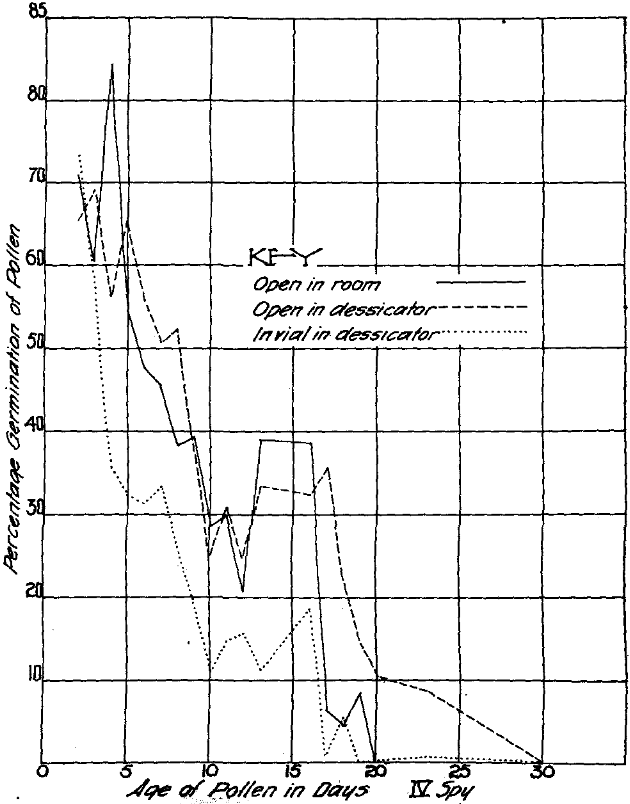

FIG. 11.—Influence of age on germinability of Spy pollen under different conditions of storage (original).

ft., 38 grains. This confirms the observations of Hockey and Harrison (1930) carried out under identical conditions. Not all the pollen, however, was wind carried. In fact, more pollen was placed on the slide by insects as indicated by its occurrence in clumps of 35 to 50 grains, while hairs and pieces of insects legs and wings were found on the slides. In other cases the scattered nature of the pollen did seem to indicate carriage by wind. In 1932 also, an experiment was conducted in which a current of air from an orchard duster was blown thoroughly through a large bouquet of blossoming apple limbs adjacent to a tree also in bloom. The large set obtained on this side of the tree, equivalent to that obtained on hand pollinated limbs, indicated that the pollen had been well distributed by this method. In spite of the foregoing, it appears that under normal conditions the effect of wind carriage of pollen is very local and is not an important factor in the pollination of the apple.

Experiments in the rate of pollen tube growth were made by pollinating Spy blossoms with pollen of different varieties and clipping the stigmas at definite intervals thereafter, and noting the set. Considerable differences were noted in the time required to effect fertilization, as measured by the set secured, between the results obtained in 1928 and those obtained in 1931, this difference being apparently correlated with weather conditions. In 1931 maximum sets were obtained in 48 hours, whereas in 1928, the 60-hour interval gave optimum results. Little consistent difference was noted between the different pollen varieties, except when Spy itself was used, in which case fertilization was delayed, but these selfing tests only gave a set of ·37 per cent, which is too small a number upon which to base conclusions.

4. EXPERIMENTAL RESULTS OF POLLINATION EXPERIMENTS WITH STANDARD VARIETIES

The results of all experiments with standard varieties are summarized in the following tables and discussion. In view of the importance of chromosome constitution in the behaviour of varieties, it has been considered advisable to classify the crosses as, (1) diploid x diploid, (2) triploid x diploid, (3) diploid x triploid and (4) triploid x triploid.

Each variety is then discussed in detail from the following standpoints:—

(i) Results obtained by other workers.

(ii) Value from the standpoint of self-fruitfulness as determined by "set" and "fruit" secured.

(iii) Value as a female parent, using the same criteria.

(iv) Value as a male parent considering "set," "fruit" and "seeds" produced. The "per cent seeds" in our tables is calculated from the 1930 and 1931 figures only, as indicated below:—

Variety	Total blossoms	Total seeds
Baldwin	18,985	1,410
Cox Orange	22,388	11,548
Golden Russet	21,584	11,972
Gravenstein	16,613	3,117
King	22,742	2,820
Spy	4,767	2,578

(v) Evidence from tent series.

(vi) Summary of results with all varieties.

(vii) Other data, if any.

(viii) General summary for variety.

Finally, a general summary based on the results of tent and hand pollination studies, with special emphasis upon findings of a fundamental nature, is presented.

(a) BALDWIN

(i) *Results of Other Workers.*—MacDaniels (1927) in a summary of pollination studies with this variety, illustrates that self-fruitfulness is not a fixed factor in that or any variety, but varied greatly according to differences in environmental or other conditions. Other workers, Overholser, (1927), Morris (1921), MacDaniels and Heinicke (1929) and Howlett (1927) all record this variety as either self-fruitful or partially self-fruitful. Furthermore, all workers record Baldwin as an excellent female parent, but poor, or at best, only fair as a male parent.

(ii) *Results of Selfing Tests on Baldwin (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
6,856	1,711	24·96	437	6·37

The results of hand pollination tests at the Experimental Station with this variety, indicate that it is very self-fruitful compared with all other varieties tested. The selfing tests over a period of five years show a percentage "set" of 24·96 and of "fruit" 6·37. It should be emphasized, however, that, though Baldwin is very self-fruitful and gives, when selfed, a better yield than with many other varieties, it does not give as good results as when crossed with highly cross-fruitful varieties such as Cox Orange.

(iii) *Results from Baldwin as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
28,178	11,672	41·42	3,232	11·47

Its value as a female parent is high, as indicated in the above table, giving a percentage "set" of 41·42 and a percentage "fruit" of 11·47. All diploids tested on Baldwin, such as Cox Orange, Golden Russet, and Spy, proved to be effective pollinizers for the variety. McIntosh and Wagener were tested in 1932 only, and gave every indication of being equally as effective as the other diploids tested over the longer period.

(iv) *Results from Baldwin as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
26,841	2,974	11·08	681	2·54	7·43

By all criteria used Baldwin gives relatively poor results as a male parent, the per cent "set" for the five-year period being 11·08, the per cent "fruit" 2·54, and the per cent seed 7·43.

(v) *Evidence from Tented Series.*—Additional evidence from tent studies shows that self-fruitfulness takes place to a very marked degree, the tented trees (with bees and no bouquets) over a four-year period (1929-1932) giving an average percentage fruit of 7·77. The untouched tree (no bees and no bouquets), over the same period, only gave a percentage fruit of 3·49, indicating that selfing cannot take place to a satisfactory degree without the aid of pollinating insects. The open pollinated tree, representing results from a mixture of various pollens,

FIG. 12.—Photographs illustrating results of experimental pollinations: (1) Baldwin selfed; (2) Baldwin x Cox Orange; (3) Baldwin x King (original).

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gave 10·40 per cent fruit over a four-year average, while the tree with bees and Blenheim bouquets, over the same period, resulted in 4·96 per cent, indicating cross-unfruitfulness between these two varieties. On hand pollinated limbs used in the tent studies, we find an effective pollinizer like Cox Orange to give an extremely high percentage, where the yield over the whole tree is reduced as in the case of the treatments, *e.g.*, the trees with no bees and no bouquets. Limbs hand pollinated with an ineffective pollinizer in the tented series gave a low percentage fruit, indicating similar results to that of whole trees tented and treated in a similar manner.

(vi) *Summary of Results with all Varieties on Baldwin (1928-1932).*

Cox Orange		G. Russet		Gravenstein		King		Spy	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
5,718	*14·64*	*5,761*	*12·25*	*5,186*	*8·93*	*5,436*	*8·65*	*6,077*	*12·44*

The above tests show that the triploid varieties, mainly Gravenstein and King, gave satisfactory results when used as male parents on Baldwin. However, the possibility that a percentage of this is due to selfing cannot be excluded, and, if emasculation tests were practised, the results from these sorts might have been lower. That selfing may not be the entire explanation is indicated by the fact that the pollen of certain triploids when used on Baldwin gave a percentage fruit considerably in excess of those obtained by selfing, as indicated elsewhere.

This brings forth the necessity of further work under emasculated conditions to determine the true value of these male parents. All the diploids tested, Cox Orange, Golden Russet and Spy gave slightly higher results than the mentioned triploids and may be readily termed as excellent pollinizers for Baldwin.

(vii) *Other Data.*—A considerable number of blossoms were pollinated with R. I. Greening pollen during the season of 1932 to determine its value as a male parent. The results from this triploid were very unusual, a percentage fruit of 14·86 being obtained from a population of 1,521 blossoms. Other triploids such as Nonpareil and Blenheim gave depressing effects when used as bouquets in tented trees with bees.

(viii) *General Summary for Variety.*—This variety exhibits a high degree of self-fruitfulness, 24·96 per cent "set" and 6·37 per cent "fruit" over five-year period, the highest for any variety tested. The bagged and untouched blossoms gave a very low per cent fruit, ranging from 3·70 on the open pollinated trees, to 1·01 on the tented trees supplied with bees and no bouquets, i.e. selfed, over a four-year period. As a female parent Baldwin stands high, giving an average of 11·47 per cent for the varieties tested over a period of five years, this figure being larger than the open pollinated average of 10·40 per cent for a four-year period. Baldwin, being classified as a triploid, might be expected to, and actually does, give relatively poor results as a male parent, 2·54 per cent being obtained on the varieties tested.

It should be understood that Baldwin is a markedly biennial bearer and that our tests had, therefore, to be made on different trees each year, trees being selected that had not blossomed or had not blossomed heavily the previous year. This habit markedly diminishes its commercial value. It is known, however, as a reliable cropper every other year, almost invariably bearing crops when bloom is obtained, whereas, certain other varieties are notably uncertain. The high degree of self-fruitfulness exhibited by this variety is, no doubt, associated with this habit.

(*b*) COX ORANGE

(i) *Results of Other Workers.*—Crane (1926) lists this variety as partially self-fruitful, and points out that the trees bear early. Only moderate crops result from selfing and full crops when crossed. Auchter (1921) of Maryland classifies Cox Orange as self-fruitful, while on the other hand, Corrie (1916), Sutton (1919) and Hooper (1921) place it as self-sterile or self-unfruitful. Crane and Lawrence (1930) classify it as a diploid, thus indicating its value as an effective male parent.

(ii) *Results of Selfing Tests on Cox Orange (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
9,016	1,136	12·60	163	1·81

The hand pollinated results at Kentville indicate that this variety gave a low percentage " set " and " fruit " in selfing tests, the average for five years being 12·60 and 1·81 respectively. The latter figure indicates a low value from the standpoint of self-fruitfulness and the necessity of the provision of cross-fruitful varieties in order to secure commercial crops.

(iii) *Results from Cox Orange as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
37,091	10,526	28·38	2,869	7·74

As a female parent the average figure over a five-year period was 7·74, this result being obtained by using pollen from standard varieties. This figure is higher than that obtained from open pollinated trees, which gave a percentage fruit of 6·74, over a four-year period. All diploids tested, Golden Russet, McIntosh and Wagener, proved effective pollinizers on Cox, excellent results being evident in each case.

(iv) *Results from Cox Orange as Male Parent (1928-1932)*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
27,890	9,638	34·56	3,202	11·48	51·58

As a male parent this variety proved excellent in all cases, the five-year average being 11·48 per cent fruit. This result is in line with that obtained with all diploid varieties tested and enhances the value of this variety in commercial plantings. The high percentage seed obtained by the use of this variety is confirmatory of the " set " and " fruit " figures.

(v) *Evidence from Tented Series.*—This variety was not included in the tented series, thus our information, pertaining to self-fruitfulness, is confined entirely to hand pollination tests.

FIG. 13.—Photographs illustrating results of experimental pollina- [illegible] Orange selfed; (2) Cox Orange x Golden Russet;

(vi) *Summary of Results with All Varieties on Cox Orange (1928-1932).*

Baldwin		Gravenstein		Golden Russet	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
6,376	2·51	6,586	4·97	6,190	13·99
King		McIntosh		Wagener	
6,887	2·47	5,186	10·99	5,866	13·23

The triploid varieties, namely, Baldwin, Gravenstein, and King, gave uniformly poor results on Cox. The diploids, Golden Russet, McIntosh and Wagener, on the other hand, gave excellent results throughout, indicating clearly that only such sorts should be used to pollinate Cox Orange.

(vii) *Other Data.*—To illustrate the value of cross-pollination, where solid blocks of one variety are planted, several limbs were hand pollinated with Cox Orange pollen in a ten-acre block of solid Blenheim at Lakeville. The results were very significant, since, in all cases where Cox was used, a heavy percentage fruit, varying from 20 to 75, resulted, this being an extreme contrast to the remainder of the block in which the set was light and scattering, in most cases below one per cent. This experiment was repeated on a small scale in a large number of orchards where Blenheim were reported to be giving poor returns. In all cases, the results were marked and, in many, very spectacular; the hand pollinated limb being laden with fruit in contrast to the other limbs with few or none. Similar, but less spectacular results were obtained on Stark.

(viii) *General Summary for Variety.*—This variety may be considered to be commercially self-unfruitful on the basis of a five-year average, although a low percentage of fruit was obtained in most selfing tests. It is an excellent male parent, giving satisfactory results for all varieties that blossom at approximately the same time and, being somewhat irregular in its blossoming habits, it is useful on an unusually large range of varieties. As female parent in hand pollinated tests, Cox has given a high average percentage fruit, the figure averaging higher than the open pollinated results.

(c) GOLDEN RUSSET

(i) *Results of Other Workers.*—Sax (1922) states, that, for practical purposes, all Maine apples are "self sterile" from the commercial standpoint. Ben Davis, Baldwin, *Golden Russet*, R. I. Greening, Northern Spy are all mentioned as "interfertile," with the exception of Greening and Baldwin, as pollen parents.

(ii) *Results of Selfing Tests on Golden Russet (1928-1932).*

Total blossoms	Total set	Per sent set	Total fruit	Per cent fruit
8,016	1,009	12·59	139	1·73

Golden Russet shows a fair degree of self-fruitfulness under the conditions of these experiments. This variety is rather variable in its bearing habits, and when grown on the heavier soils appears to be more fruitful. The average figure from selfing over five years is 12·59 per cent "set" and 1·73 "fruit," indicating a low average value from the standpoint of self-fruitfulness.

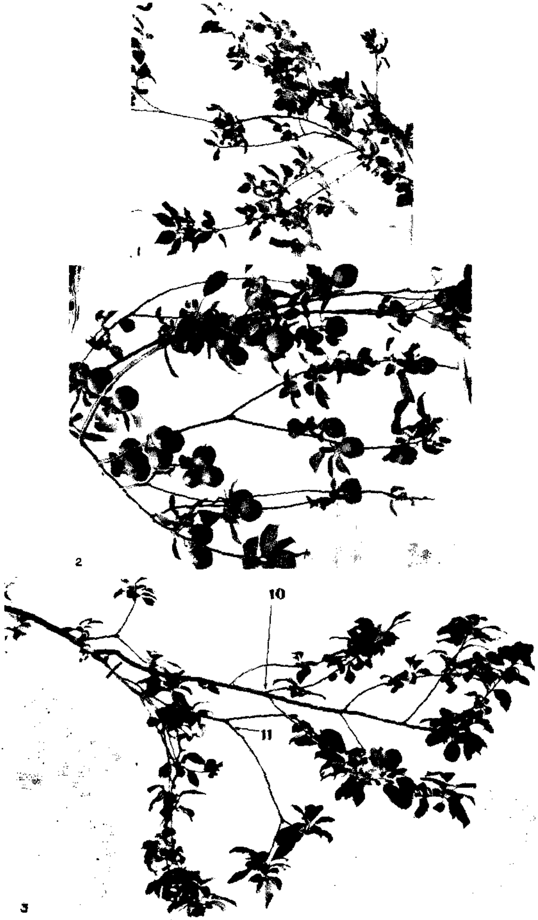


FIG. 14.—Photographs illustrating results of experimental pollinations: (1) Golden Russet selfed; (2) Golden Russet x McIntosh; (3-10) Golden Russet x Baldwin; (3-11) Golden Russet selfed (original).

(iii) *Results from Golden Russet as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
25,377	5,335	21·02	1,042	4·11

Our results show Russet to be rather poor as a female parent, the average being 21·02 per cent "set" and 4·11 "fruit" (1928-1932). McIntosh and Cox Orange were the only diploids tested on this variety, both proving very satisfactory pollinizers. As indicated previously, the percentage fruit to bloom is considerably lower on the light sandy soil at Kentville than appears to be the case on the heavier types of soil, such as are found in Lakeville and similar districts. Thus, the value of Golden Russet as a female parent may vary to a marked degree, depending upon the locality in which the tests are made and the conditions under which it is grown.

(iv) *Results from Golden Russet as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
28,341	10,993	38·79	3,185	11·24	55·47

As a male parent Golden Russet is in the front rank giving an average per cent "set" and "fruit" and "seed" of 38·79, 11·24 and 55·47 respectively. Being a desirable commercial variety it is particularly valuable as a pollinizer in any scheme of orchard planting.

(v) *Evidence from Tent Series.*—Tented tests were not conducted with this variety, thus all information available as to its self-fruitfulness is limited to the hand pollinated tests.

(vi) *Summary of Results with All Varieties on Golden Russet (1928-1932).*

Baldwin		Cox Orange		Gravenstein		King		McIntosh	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
5,333	2·33	5,355	7·51	4,995	2·28	5,767	2·15	3,927	7·08

Baldwin, Gravenstein and King varieties gave poor results throughout, as one might well expect, these varieties being triploids. Cox Orange and McIntosh, as pointed out previously, produced excellent results and one may reasonably assume, on the basis of similar tests, that any diploid, with suitable overlapping of the blossoming periods, would prove satisfactory as a pollinizer for Golden Russet.

(vii) *Other Data.*—To illustrate further the point regarding the varying degrees of self-fruitfulness in relation to locality, we find that the hand pollinated tests conducted in a Golden Russet orchard on a heavy loam soil at Wolfville gave a percentage fruit of 6·34 as a female parent. This figure is over two per cent higher than the five-year average. This is in line with the current opinion with respect to this variety, though the possibility of other factors influencing the foregoing result is not excluded.

(viii) *General Summary for Variety.*—Although Golden Russet is listed as "self sterile" in Maine, our selfing results indicate a rather low degree of self-fruitfulness, with considerable variation from year to year. As a male parent, it is very effective, being equally as good as Cox Orange and Spy in this respect. Its value as a female parent has been elaborated in the foregoing discussion and may be considered of variable nature, tending to be poor on the lighter types of soil. McIntosh and Cox Orange are the only satisfactory pollinizers tested.

(*d*) GRAVENSTEIN

(i) *Results of Other Workers.* Overholser (1927) states that this variety is self-unfruitful, giving a per cent set of ·09. His work further showed that Gravenstein was an ineffective pollinizer for R. I. Greening, Jonathan, Delicious and Baldwin. He found Delicious to be an effective pollinizer for the variety. Morris (1921) lists Gravenstein as a partially self-fruitful variety, as also does Vincent (1915). However, we find the latter cases to be the only exceptions to the general belief that Gravenstein is highly self-unfruitful. Wellington, Stout, *et al.* (1929), working in New York state, obtained no set where selfing was practised. The majority of writers record Gravenstein as a good female parent and wherever diploid varieties are used as male parents, good yields are obtained. On the other hand, due to the fact that it is a triploid, we find it giving poor results wherever used as a male parent.

(ii) *Results of Selfing Tests on Gravenstein (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
7944	193	2·43	91	1·15

In the hand pollinated selfing tests at Kentville, Gravenstein has proven to be the most self-unfruitful of the six standard varieties under test, the average for five years being 2·43 per cent "set" and 1·15 per cent "fruit," the figures based on a count of nearly 8,000 blossoms.

(iii) *Results from Gravenstein as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
32,225	6,876	21·34	3,048	9·46

As a female parent, Gravenstein may be considered good, giving average per cent "set" of 21·34 and "fruit" 9·46. Cox Orange, McIntosh, Golden Russet and Wagener, all diploids, are excellent pollinizers for the variety and when interplanted should give maximum results.

(iv) *Results from Gravenstein as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
21,911	4,729	21·58	1,114	5·08	18·76

As a male parent, although not as poor as Baldwin and King, it has not been at all satisfactory. The results show an average percentage of 21·58 "set," 5·08 "fruit" and 18·76 seeds. The latter figures are higher than might be expected, keeping in mind the fact that this variety is a triploid form. Of all this group it has given in our tests the highest value as a male parent.

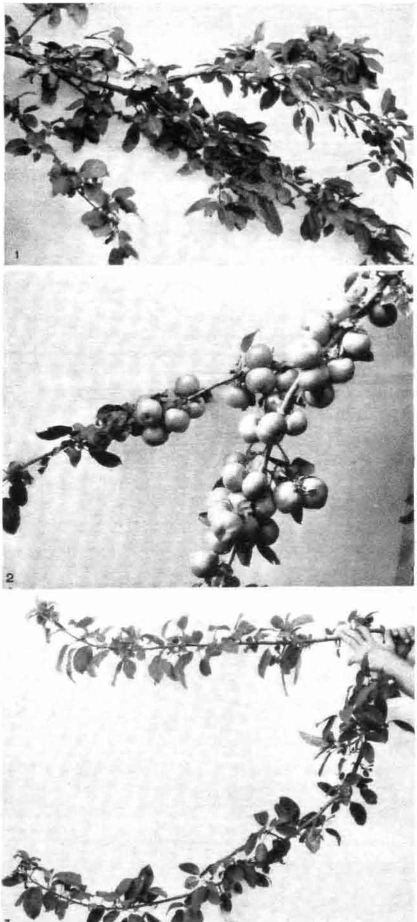


Fig. 15.—Photographs illustrating results of experimental pollinations: (1) *Gravenstein selfed*; (2) Gravenstein x Wagener; (3) Gravenstein x King (original).

(v) *Evidence from Tented Series.*—It is interesting to note the degree of self-fruitfulness which occurs in the tented series over a period of four years. The tented tree with bees and no bouquets (selfed) gave an average of 2·12 per cent fruit. This figure would tend to make one believe that Gravenstein is more self-fruitful than hand pollination tests would appear to indicate. The cutting back of the trees in order to put the tents in place appeared to increase the number of seedless fruit, which Gravenstein has a tendency to produce. On the other hand the trees with no bees and no bouquets gave an average of 0·67 per cent fruit. This indicates clearly that natural selfing in the absence of bees is exhibited only to a very limited degree. Open pollinated trees showed the high percentage fruit of 9·91 and, where an effective pollinizer, *viz.*, Wagener, was used, 10·90 per cent of fruit was obtained. In the cases where Blenheim bouquets were introduced we find the average over the four years reduced to 1·14 per cent fruit, the latter figure being less than that of the self-pollinated trees. The hand pollinated results in the tented series show Wagener to be an excellent male parent and a percentage fruit of 47·11 was obtained from individual hand pollinated limbs on the untouched trees (*i.e.* no bees and no bouquets) over the four-year period. On the open pollinated tree, the limb hand pollinated with Wagener only gave a percentage fruit of 11·21. This illustrates the fact that the results obtained on hand pollinated limbs are in direct proportion to the total crop borne by all limbs over the entire tree.

(vi) *Summary of Results with All Varieties on Gravenstein (1928-1932).*

Baldwin		Cox Orange		Golden Russet	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
4,854	0·87	5,441	15·25	5,164	12·72
King		McIntosh		Wagener	
5,857	1·52	5,030	12·01	5,876	14·06

The triploid varieties, namely Baldwin and King, tested on Gravenstein gave uniformly poor results throughout, indicating the inadvisability of interplanting Gravenstein orchards with such varieties. All diploids tested on this variety gave excellent results, as the above table indicates, and the varieties chosen to inter-plant with Gravenstein depend largely on individual preference, location, soil type, and market demand.

(vii) *Other Data.*—Unfavourable weather prevailed during the 1931 season. Three of the hand pollinated limbs in the tented series were pollinated on May 23, the remaining three on May 25. The former gave an average percentage fruit of 27·85, the latter 8·60 per cent. The preceding figures indicate that a higher yield is obtained if pollination is carried out when the stigmas are first receptive rather than near the end of stigma receptivity. That is to say, pollination results appear to be more favourable when the blossom first opens. This result was consistent with other varieties observed.

(viii) *General Summary for Variety.*—Gravenstein is the most self-unfruitful of the standard varieties grown in the Annapolis valley. In view of the fact that it is a triploid, it makes a rather poor male parent. As a female parent, this variety may be considered good and when such pollinizers as Cox Orange, Golden Russet, McIntosh and Wagener, all diploids, are present, excellent results are obtained.

(*e*) KING

(i) *Results of Other Workers.*—Overholser (1927) in studies in California found King to be self-unfruitful. Furthermore, he found it to be a very unsatisfactory male parent, being similar to Baldwin in this respect. He found King

FIG. 16.—Photographs illustrating results of experimental pollinations: (1) King selfed; (2) King x Wagener; (3) King x Baldwin (original).

be a fair female parent, with Jonathan proving the most effective pollinizer. rane and Lawrence (1929), in experiments conducted at Merton, England, find ling to be partially self-fruitful, a percentage set of 1·9 being obtained. Wel-ngton, Stout, *et al.* (1929), found this variety to be also partially self-fruitful n New York state, while Auchter (1921) lists it as self-fruitful in Maryland. Other workers, *e.g.*, Morris (1921); Chittenden (1926), and Lewis and Vin-ent (1909) place King as a self-unfruitful variety. As a male parent the above writers find it poor. Wellington, Stout, *et al.* (1929) found Delicious to be an effective pollinizer for King, good commercial sets resulting.

(ii) *Results of Selfing Tests on King (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
7,221	1,072	14·85	257	3·56

The results over five years indicate that King is fairly self-fruitful, selfing tests giving an average percentage "set" of 14·85 and "fruit" 3·56. This figure may even be considered self-fruitful for the variety, because of the fact that the open pollinated trees over the period tested gave only 4·74 per cent fruit. In this connection also should be considered the large number of blossoms produced by this variety, the large size of the fruit and the annual bearing habit of the King in many commercial orchards.

(iii) *Results from King as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
32,148	6,648	20·68	1,549	4·82

King as a female parent may be considered good, a "set" of 20·68 and "fruit" of 4·82 per cent, being obtained over the five-year period. The above figure is extremely good when one takes into consideration the fact that between 3·5 and 4 per cent fruit on a heavy blossoming tree will result in a good commercial crop, with this variety. The diploids tested, Cox Orange, Golden Russet, McIntosh and Wagener, all increased the "set" and "fruit" percentage above that of selfing and above that obtained where triploids were used. It should be noted that a small increase of one half of one per cent is of great economic importance in this variety, because of the low percentage fruit necessary to give a satisfactory crop.

(iv) *Results from King as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
29,941	3,458	11·55	1,068	3·57	12·40

This variety may be considered very unsatisfactory as a male parent, being similar to Baldwin in this respect. The results for the past five years show a percentage "set" of 11·55, "fruit" of 3·57 and seed, 12·40, which is quite in line with the results of other triploid varieties.

(v) *Evidence from Tented Series.*—The tent studies indicate that King is commercially fairly self-fruitful. The "untouched" tests, that is, the tented trees with no bees and no bouquets, gave a percentage fruit of only 1·03. The

open pollinated, with a percentage fruit of 4·74, exceeds the selfed trees by a little over one per cent, the latter having an average of 3·32 per cent fruit for the past four years. In the cases where Wagener bouquets were introduced as a means of cross-pollination, the per cent fruit was increased nearly one per cent, the average figure being 5·42. On the other hand, in those trees where Blenheim was used, the per cent fruit closely approached that of selfing, namely 3·58. It might be well to state that King shows less difference between different male parents than any variety tested, a habit associated with the very low percentage fruit to spur area. Even though the original set may show considerable differences, dropping takes place until the margin between crossing and selfing results is greatly reduced.

(vi) *Summary of Results with All Varieties on King (1928-1932).*

Baldwin		Cox Orange		Golden Russet	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
5,790	4·27	5,530	5·08	5,084	4·33
Gravenstein		*McIntosh*		*Wagener*	
5,144	4·08	4,565	5·56	6,035	5·58

The triploids, namely, Baldwin and Gravenstein, gave much better results on this variety than one might expect, both showing an increase of one-half of one per cent over the selfing tests. All the diploids, Cox Orange, Golden Russet, McIntosh and Wagener, gave an increase of one per cent over the selfed tests and from one-half to one per cent over the triploids used. This increase might appear of little importance in some varieties, but in the case of King, with its normally low per cent of set to bloom, it is significant.

(vii) *Other Data.*—The results obtained during 1931 in a King orchard at Wolfville, were uniformly lower than those obtained at Kentville in 1928, 1929, 1930 and 1932. This may be explained by the fact that the trees in the Wolfville orchard are in an annual-bearing habit, whereas those used in Kentville were decidedly biennial.

(viii) *General Summary for Variety.*—In summarizing the results from this variety it may be stated that King is fairly self-fruitful from a commercial standpoint. As a male parent it is rather poor, being next in line to Baldwin; as a female parent it is good, when one takes into consideration its blossoming and bearing habits, together with the large size of individual fruits. Triploid crosses such as Baldwin and Gravenstein do not depress fruitfulness, as was found to be the case when used with most other varieties tested, and all the diploids tested showed their value as pollinizers by increasing the percentage fruit to bloom, to the extent of one per cent iu most cases.

(l) NORTHERN SPY

(i) MacDaniels (1928) in experiments in New York, reports Northern Spy as self-unfruitful and found that, where pollen was not applied by hand, total crop failure followed. Much greater variation in response to pollination is found in trees of low vigour than in those growing under better conditions. MacDaniels (*loc. cit.*) lists the suitable pollinizers for Northern Spy as Wealthy, Golden Delicious, Rome Beauty, N.W. Greening, Tolman Sweet, and Delicious. However, because of the late blooming habit of Spy, Rome is the only dependable source of pollen. Marshall, Johnson, *et al.* (1929), in Michigan, find Spy self-unfruitful, but place it as an effective pollinizer and as a good female parent.

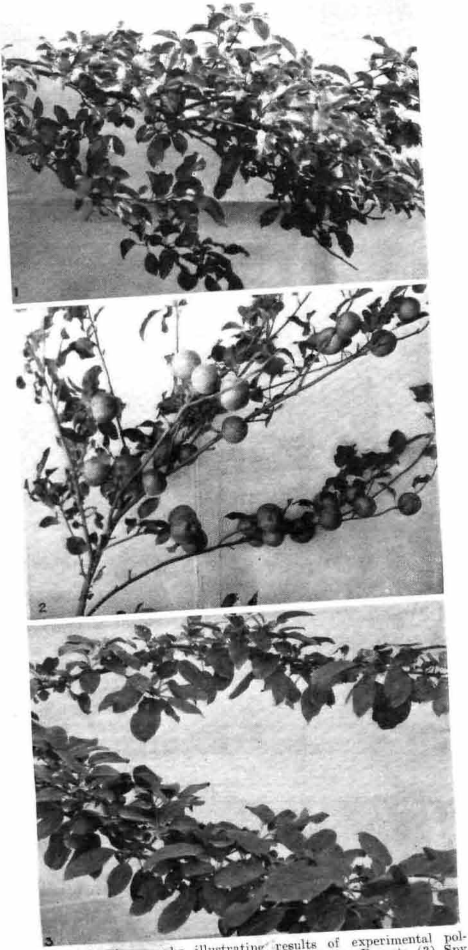


FIG. 17.—Photographs illustrating results of experimental pollinations: (1) Spy selfed; (2) Spy x Golden Russet; (3) Spy x Baldwin (original).

With one exception, *viz.*, Gowen (1920), who obtained results indicating partial self-fruitfulness, all investigators term Northern Spy self-unfruitful, but record the variety as an excellent male and female parent.

(ii) *Results of Selfing Tests on Spy (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
5,862	249	4·25	78	1·33

The hand pollinated results at Kentville during the years 1928-1931, inclusive, proved the variety to be quite self-unfruitful, yielding an average of 4·25 per cent "set" and 1·33 per cent "fruit". This figure approaches that secured in Gravenstein selfing tests, and may be considered the second lowest, in regard to self-unfruitfulness, among the six standard varieties under test.

(iii) *Results from Spy as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
27,252	7,467	27·40	2,673	9·81

Spy is an excellent female parent, 27·40 per cent "set" and 9·81 per cent "fruit" being obtained over the period. The diploid sorts gave very satisfactory results on this variety, Ben Davis being especially good. Triploids proved, on the other hand, to be unsatisfactory as male parents for Spy, and in many cases no fruit was obtained. Other varieties tested at the Kentville station, but not reported in this paper, are Delicious, Golden Delicious and Red Rome Beauty, all of which gave good results and all overlap the Spy in bloom to a satisfactory extent.

(iv) *Results from Spy as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
6,077	2,838	46·70	756	12·44	54·08

The above results, as to the value of Spy as a male parent, are based entirely on pollinations made on the Baldwin variety, and from these it may be considered an excellent pollinizer for the late blooming varieties. Spy was also used in 1928 and 1929 as a male parent for Cox Orange and Golden Russet, a per cent "fruit" of 14·44 and 10·60 respectively being obtained.

(v) *Evidence from Tented Series.*—The results from the tented series indicate that Spy is quite self-unfruitful, a percentage "fruit" of 2·00 being obtained from the selfed trees (bees and no bouquets) in the past four years. The untouched trees (no bees and no bouquets) gave a percentage fruit of 0·85, for the same period, which is nearly one per cent lower than the selfed trees, and shows that natural selfing in the absence of bees is very low. In the case of open pollination, we find a relatively high percentage fruit of 8·83 and, where an effective pollinizer was used, the per cent fruit was 10·05. In contrast to this,

where an ineffective pollinizer was tried, the fruit was reduced to 2·70 per cent, almost as low as the selfed trees. The fact that triploids were used as ineffective pollinizers in this case explains the low fruit percentage.

(vi) *Summary of Results with All Varieties on Spy (1928-1932).*

Baldwin		Ben Davis		Cox Orange		G. Russet		King	
Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit	Total blossoms	Per cent fruit
4,488	2·41	4,785	15·92	5,843	14·58	6,142	11·98	5,994	3·59

The triploids, Baldwin and King, when used as male parents give very unsatisfactory results, a very low per cent fruit resulting. Ben Davis, Cox Orange and Golden Russet are effective pollinizers; the first of these is most outstanding, the blooming periods overlapping satisfactorily, but Cox Orange gives fair results.

(vii) *Other Data.*—Tests conducted in an orchard at Greenwich, as to rate of pollen tube growth within this variety, incidentally showed Ben Davis, Cox Orange and Golden Russet to be the outstanding pollinizers under test.

(viii) *General Summary for Variety.*—We may consider Spy quite self-unfruitful, being like Gravenstein in this respect. It is excellent as a male anc female parent; our figures show it to be superior in the former respect. Ben Davi and Cox Orange are the only suitable pollinizers reported on. Rome Beauty is a excellent male parent for the variety, and being a late blossoming variety is thu a dependable source of pollen, but, in view of the fact that it has little economi importance as yet in the Annapolis valley, no tests have been conducted t ascertain its value under our conditions.

The summarized results from the standpoint of "set" and "fruit" a included in table 8 and the result by groups, including also seed data in table

TABLE No. 8.—TOTAL RESULTS OF APPLE CROSSES WITH STANDARD VARIETI
(1928-1932)

Female Parent	Male Parents											
	Baldwin		Cox Orange		Gravenstein		Golden Russet		King		Spy	
	Per cent set	Per cent fruit	Per cent set	Per cent fruit	Per cent set	Per cent fruit	Per cent set	Per cent fruit	Per cent set	Per cent fruit	Per cent set	c f
Baldwin	24·96	6·37	48·46	14·64	37·54	8·93	46·00	12·25	26·97	8·65	46·70	[illegible]
Cox Orange	16·19	2·51	12·60	1·81	19·86	4·97	49·39	13·99	11·72	2·47	......	.
Golden Russet	8·42	2·33	37·67	7·51	12·69	2·28	12·59	1·73	9·57	2·15	......	.
Gravenstein	2·33	0·87	28·95	15·25	2·43	1·15	32·86	12·72	2·78	1·52	......	.
King	18·89	4·27	18·26	5·08	16·33	4·08	23·94	4·33	14·85	3·56	......	.
Spy	6·37	2·41	38·75	14·58	......	......	38·62	11·98	7·84	3·59	4·25	

TABLE No. 9.—THE FRUITFULNESS OF DIFFERENT TYPES OF CROSSES (1928-1932)

Cross	Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Seeds* Per cent	Seeds* Average number per fruit
Diploid x Diploid	43,294	17,790	41·09	5,242	12·11	75·70	7·07
Diploid x Triploid	46,426	5,538	11·93	1,342	2·89	9·93	4·04
Diploid Selfed	22,894	2,394	10·46	380	1·66	6·38	4·36
Triploid x Diploid	60,284	19,573	32·47	6,308	10·46	36·79	4·41
Triploid x Triploid	32,267	5,623	17·43	1,521	4·71	13·49	3·47
Triploid x Triploid (without Baldwin as Female Parent)	21,645	2,210	10·21	588	2·72	6·81	3·39
Triploid Selfed	22,021	2,976	13·51	785	3·56	9·04	3·11

*Seed counts made on basis of actual number of fruit harvested.

(h) SEED CONTENT IN RELATION TO FRUITFULNESS

Pollen of high germinability and good quality for crossing together with relatively high seed content is associated with diploidy in apples, the reverse with triploidy. Diploid varieties, as female parents, have consistently given a higher seed content than triploid varieties and within the variety the seed content is affected by the male parent, diploids giving more seeds than triploids in this respect. Although diploid x diploid and triploid x diploid crosses are of approximately equal value as to fruitfulness, the latter has a much lower average seed content. Furthermore, though triploid crosses often exceed diploid x diploid in fruitfulness, the latter produced a higher average seed content in these tests. Percentage fruitfulness is generally proportional to seed content but is not necessarily directly so, as explained above.

In seed germination, triploids as a group show a much lower germination than diploids, *i.e.*, when used as females; on the other hand the male parent has no measurable effect on germination.

The results from the standpoint of viable seedlings resulting from the foregoing types of crosses, are consistent with those obtained with seed. The order of seedling production was the same, *viz.*: (1) diploid x diploid, (2) triploid x diploid, (3) diploid x triploid and (4) triploid x triploid. Details are discussed in another paper.

(i) RELATION OF SEED CONTENT TO WEIGHT

As already indicated, many workers have claimed a correlation between weight and seed content in the apple. The fact that one-sided apples show some of the carpels empty on the corresponding side is a matter of general observation. Samples picked at random offer little evidence in this connection, since many factors influence size and weight of fruit, and a disturbing factor is introduced in the utilization of fruits resulting from mixed pollination. On the other hand, trees with a very low set due to an unfruitful cross produce few apples, and those that do set may grow abnormally large due to favourable nutritional conditions. For this reason, it appears desirable that the samples selected should be produced under uniform and normal conditions. For the foregoing reason in 1931 we selected two varieties, Gravenstein, as representative of a triploid variety with very low seed content, and Northern Spy, representative of a diploid variety with an exceptionally high seed content. For our study we selected a tented tree of each variety which had been provided with a hive of bees and an effective pollinizer, Wagener in the case of Gravenstein, Ben Davis in the case of

Spy. All the apples on each tree were taken, 500 in the case of Gravenstein and 1,596 in the case of Spy. By thus providing optimum conditions for pollination we naturally reduced the production of abnormal apples likely to result from imperfect fertilization, which undoubtedly affected the results, but gave a value for the effect of seed content.

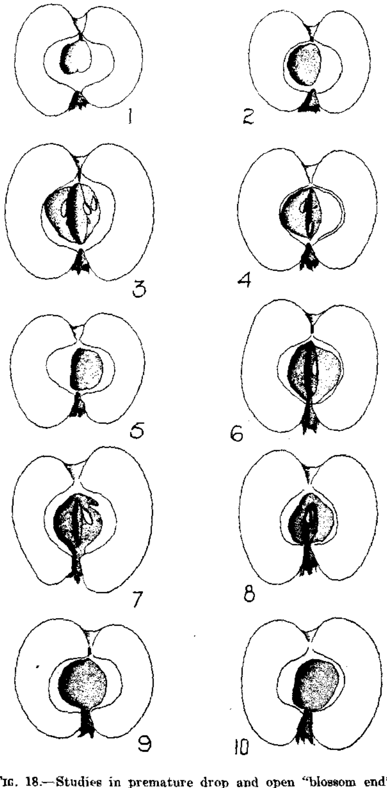


FIG. 18.—Studies in premature drop and open "blossom end" of Gravenstein: (1)-(5) closed "blossom end", no mouldy core; (6)-(10) open blossom end, mouldy core; (1) 8 seeds; (2) 6 developed and 2 undeveloped seeds; (3) 5 developed and 2 undeveloped seeds; (4) 5 seeds; (6) 1 seed; (7) 3 seeds; (8) 3 seeds; (9) 2 developed and 1 undeveloped seed; (10) no seeds (original).

The coefficient of correlation using all seeds, whether filled or not, was, in the case of Gravenstein ·055± ·0366, which is not significant; and for Spy, ·3467± ·0148, which is statistically just significant. Since results with Gravenstein are not in line with those obtained by Einset (*loc. cit.*) and since the correlation in the case of Spy is not as great nor as striking as might have been expected, it was decided to duplicate the work with Gravenstein and Spy and, in addition, to run similar correlations with King pollinated with Wagener and Baldwin pollinated with Cox Orange. The following numbers of fruits examined were: Gravenstein, 1,100; Spy, 1,000; King, 314, and Baldwin, 1,000.

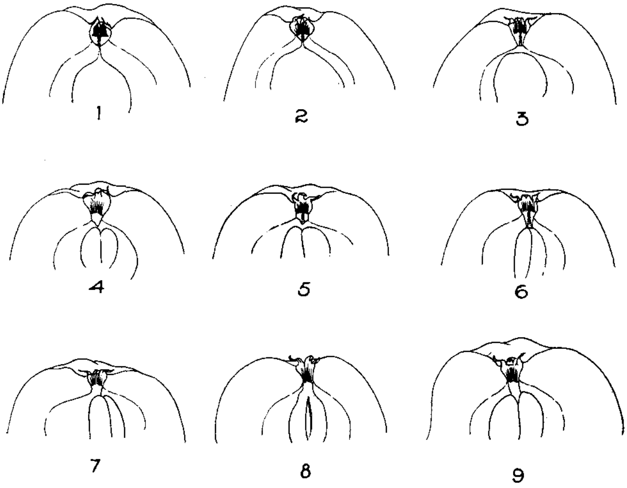


FIG. 19.—Outlines of "blossom end" of Gravenstein apples showing gradation in open condition (original).

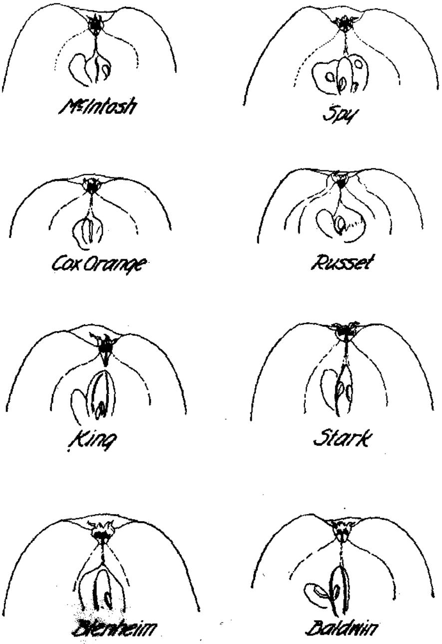
The coefficients of correlation obtained in 1932 are as follows: Gravenstein, ·0025± ·0302; King, ·1103± ·0557; Baldwin, ·2723± ·0293; Spy, ·3069± ·0286. In the Gravenstein, King and Baldwin varieties, no significant correlation was obtained, but in the case of the Spy the result may be considered just significant.

In order to determine whether chromosome constitution had a bearing on this phenomenon, another diploid, viz., Wagener was selected and a correlation calculated on one thousand apples from open pollinated trees. The correlation obtained was ·07304 and ·0315, which was not significant. It may be noted that the average number of seeds obtained for Wagener, viz., 5·58, is no greater than for Baldwin and certain other triploid varieties.

j) MORPHOLOGICAL ABNORMALITIES ASSOCIATED WITH SEED CONTENT

In varieties with a normally high seed content the failure of seed on one side to develop results in the fruit being flattened on the corresponding side. Determinations of seed content from normal and one-sided apples of the same variety show a higher average seed content and a correspondingly greater weight in the former. Varieties in which this condition was commonly observed are: Spy, Yellow Bellflower and Ben Davis. This type of distortion seems to be somewhat more common in apples of an elongate form than in those that are more flattened at the extremities. In certain other varieties, apples with few or no seeds may be found, which are almost cylindrical in shape. Such was the case with Deacon Jones, in which type the number of seeds is twenty, the average from mixed samples being 9·36.

On the other hand, apples with a relatively low average seed content may show no distortion whatever. In the Wageners examined by us in our studies of weight in relation to seed content, no one-sided specimens were found. The same is true of all the triploid varieties studied, viz., King, Baldwin and Gravenstein.



[illegible] "[illegible] end" of standard varieties (original).

It has already been noted in preceding sections that few-seeded and even seedless Gravensteins may be normal in size, weight and outer form. However, such apples may be characterized by abnormalities at the calyx end, which result in an open core condition, resulting in the invasion of this region by saprophytic fungi, producing what is known as "mouldy core." The late summer drop of Gravenstein, which occurs in some seasons, is also correlated with this condition. In experiments under tents it was found that trees supplied with a suitable source of cross-fruitful pollen and an adequate force of insect pollinators gave approximately one half the amount of premature dropped fruit. Furthermore, along with a higher seed content, effectively pollinated apples developed a negligible percentage of open calyx end and "mouldy core." Ineffectively pollinated trees produced fruit with a relatively low seed content and high percentage of open calyx end and "mouldy core." On the other hand, the open pollinated trees, where a measure of effective pollination had taken place, were intermediate in position.

This open blossom-end condition has also been noted in two other varieties, viz., Boskoop and Bramley Seedling. The average seed content of these varieties is low, approximating that of Gravenstein. In addition, a single tree of an unnamed variety, probably a seedling, was discovered in which few apples containing seeds could be found. On cutting open these apples, practically all exhibited this condition. The foregoing observations are based mainly upon preliminary studies made in 1932. No extensive survey of apple varieties to determine the nature and distribution of the foregoing abnormalities has been made, and much further research is needed before definite conclusions can be drawn.

5. SUMMARY, INTER-FRUITFULNESS OF APPLE VARIETIES

(*a*) POLLEN STUDIES

1. Technique followed in pollen tests:—
   (*a*) All pollen was gathered from nondehisced anthers.
   (*b*) It was matured under ideal artificial conditions.
   (*c*) It was tested in sugar-agar germinative media.

2. The original medium was a 10 per cent cane sugar solution. However, it was found more effective to use a medium containing 15 per cent cane sugar and ·5 per cent agar.

3. Counts of approximately 1,000 pollen grains were made for each variety.

4. Pollen germination tests were conducted on all available varieties.

5. The results obtained with the different varieties from year to year were not entirely consistent, but, in considering each year's germination tests, the effective pollinizers gave consistently higher germination than the ineffective pollinizers.

6. An exception to the above was Stayman Winesap which, although germinating well proved ineffective as a pollinizer, due to an agglomeration of pollen grains.

7. All pollen used on the hand pollinated series was tested for effective germination before use.

(*b*) TENT STUDIES

1. In tent studies, cages were erected over trees of four varieties, viz., Baldwin, Gravenstein, King, and Spy, each being subdivided into the following series:—

   1. Tented, with bees and an effective pollinizer.
   2. Tented, with bees and an ineffective pollinizer.
   3. Tented, with bees and no pollinizer.

4. Tented, with no bees and no pollinizer.
5. Tented, with no bees but with effective pollinizer.
6. Check tree, untented and left open pollinated, abundance of pollinating insects being present.

2. The method followed was to place bees and bouquets in required tents, without emasculation of the blossoms. Results in emasculation tests show that this method of procedure was warranted.

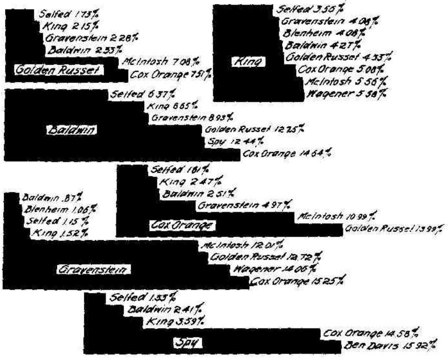


FIG. 21.—Diagram showing value of different pollens on standard varieties (original).

3. Bagged limbs used as checks on effectiveness of treatment gave consistent results, which further verifies the foregoing point.

4. The exclusion of pollinating insects reduced the crop produced to an unprofitable level in all cases.

5. In all cases, the use of an effective pollinizer has given a higher percentage fruit than where ineffective pollinizers were used.

6. The introduction of an effective pollinizer in Baldwin, Gravenstein, King and Spy has given an increase in yields over selfed trees.

7. In the case of Baldwin, a good commercial crop can be obtained by selfing.

8. Gravenstein and Spy are self-unfruitful, *i.e.* commercial crops cannot be obtained through selfing.

9. King is quite self-fruitful, giving in some years satisfactory results through selfing.

10. Wind pollination within tented trees is practically nil.

(c) HAND POLLINATION STUDIES

1. To secure a large population the limb unit method was followed.

2. Emasculation was not practised, but large populations and extreme care in pollinating before the anthers had dehisced, more than compensated for the small population that would have been necessitated had emasculation technique been practised.

3. General results with this series are in agreement with those of the tented series.

4. Baldwin and King are self-fruitful, the former to a greater degree.

5. No one variety was found to be absolutely self-unfruitful. Cox Orange, Golden Russet, Gravenstein and Spy all exhibited self-fruitfulness to a slight degree. The former two varieties were superior in this respect to the latter two.

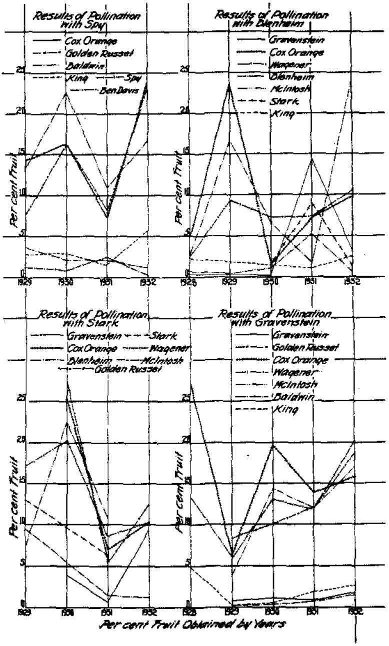


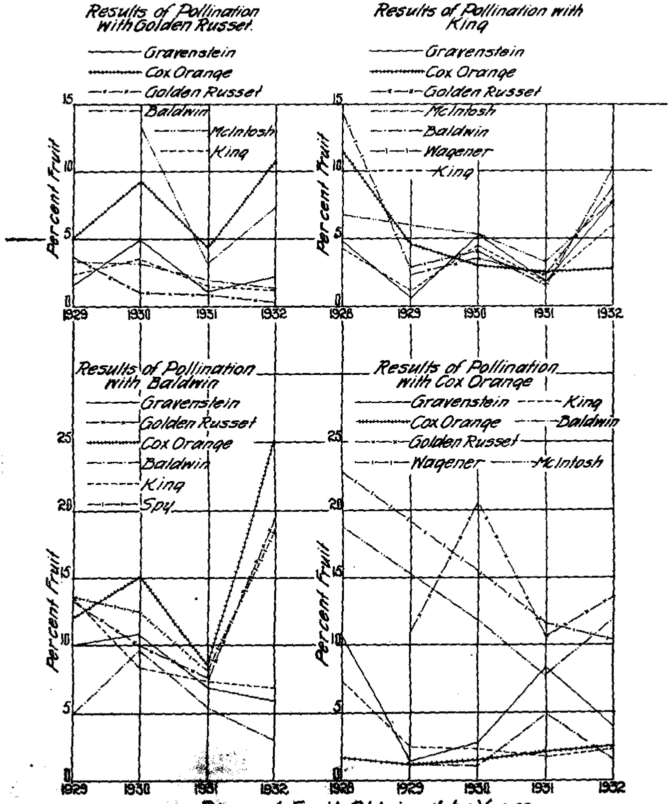
FIG. 22.—Graphs showing value of different pollens on Spy, Blenheim, Stark and Gravenstein (original).

6. As male parents, the diploids, namely, Cox Orange, Golden Russet and Spy proved excellent. On the other hand, the triploids, viz., Baldwin, Gravenstein and King gave uniformly poor results, Gravenstein being superior in this respect to the other triploids.

7. As female parents, Baldwin, Cox Orange, Gravenstein, King and Spy are good. Golden Russet's value is of a variable nature, tending to be poor on the lighter types of soils and good on the heavier.

8. The following classification of the standard varieties shows the combinations found suitable for interplanting in the Annapolis valley:—

Female	*Male*
Baldwin	x Cox Orange or Spy.
Cox Orange	x Golden Russet, McIntosh and Wagener.
Golden Russet	x Cox Orange or McIntosh.
Gravenstein	x Cox Orange, Golden Russet, McIntosh and Wagener
King	x Cox Orange, Golden Russet, McIntosh and Wagener
Spy	x Ben Davis and Cox Orange.



Per cent Fruit Obtained by Years

... Baldwin and Cox

6. GENERAL RESULTS AND CONCLUSIONS FROM STUDIES IN INTER-FRUITFULNESS

(*a*) *Owing to the mixed condition of Nova Scotia orchards the pollination* problem is not as acute as in some fruitgrowing districts. Nevertheless, clear evidence of unfruitfulness from the practice of (1) planting self-unfruitful varieties in blocks, (2) planting cross-unfruitful varieties together or (3) making inadequate provision for cross-pollination, has been obtained. With the modern movement to restrict new plantings to a smaller number of commercially desirable sorts and to cut down the number of existing varieties by "grafting-out" operations, a consideration of the pollination situation becomes increasingly important.

(*b*) The detailed results of hand pollination tests with standard varieties are shown in table 8, and the group results for the different types of crosses in *table 9. A study of the results which are based on very large populations, indi-*cates that the pollination problem is, in essence, a simple one.

(*c*) The value of a variety as a male parent is closely associated with the chromosome constitution of the variety. All diploid varieties tested gave good results as male parents for other varieties, whether diploids or triploids, while triploid varieties gave relatively poor results. When large averages are considered, there is little significant difference between the different diploids tested, and, provided there is the proper degree of synchronization between pollen liberation and stigma receptivity in the varieties concerned, all diploids may be expected, on the basis of these tests, to do about equally well, but triploids appear to be of unequal, though inferior, value. Exceptions to this general rule may occur as a result of certain mechanical factors, but the foregoing appears to be true for the varieties tested by us. Correlated with their production of a relatively large percentage of fruit when used as a male parent, a relatively high percentage pollen germination is characteristic of diploid varieties. On the other hand, a relatively low pollen germination is characteristic of triploid sorts, but pollen germination alone does not account for the results secured. They are the result of irregular chromosome distribution, which may show its effect either in preventing germination or in causing faulty development or abortion later.

(*d*) On the basis of results obtained with the varieties tested, there would appear to be little significant difference between the diploid x diploid type of cross and the triploid x diploid, both being, to a high degree, fruitful. On the other hand, diploid x triploid and triploid x triploid crosses, excluding Baldwin as a female parent owing to possible selfing, are both very unfruitful, the difference between these two groups in our tests being insignificant.

(*e*) It is by no means certain, however, that the higher average fruitfulness obtained by the triploid x triploid crosses when results from Baldwin are included, are due to selfing in the latter variety. All triploids, with the exception of Blenheim, when used as pollen parents for this variety gave average results superior to selfing, R. I. Greening conspicuously so. They are also higher than diploid x triploid crosses which may be due to the triploid x triploid cross allowing an opportunity lacking in diploid x triploid crosses for the union of diploid or near diploid gametes.

(*f*) Diploid varieties, as female parents, have a consistently higher seed content than triploid varieties. With diploid varieties the seed content is affected by the chromosome constitution of the male parent, diploids, as male parents, giving a *consistently higher seed content than triploids.*

(*g*) The value of the different varieties as female parents, or from the standpoint of selfing, is not so clearly associated with the chromosome number. Fruitful and relatively unfruitful sorts are found among both diploids and triploids. Self-fruitfulness is found in varying degrees in both groups. Of all the varieties

tested, Baldwin is the most self-fruitful. King is fairly self-fruitful, but such triploid varieties as Gravenstein and Blenheim are, ordinarily, conspicuously self-unfruitful. The results indicate the variable character of self-fruitfulness from year to year and under different conditions.

(*h*) Not only is the value of the male parents indicated by the seed content of the female parent upon which their pollen is used, but the percentage of seedlings resulting when such seed is planted, affords evidence in the same direction, which is presented in another paper published elsewhere.

(*i*) No correlation between seed content and weight could be demonstrated for Gravenstein, King, Baldwin and Wagener. Spy showed a slight correlation.

(*j*) Malformation of fruit in the form of one-sided or cylindrically-shaped apples results from imperfect fertilization in certain varieties, chiefly those with a relatively high average seed content.

(*k*) In certain other varieties with a low average seed content, a condition known as "open blossom end" results when the seed content is below normal as a result of poor pollination. In Gravenstein, imperfect pollination, "open blossom end" and "mouldy core" were found to be associated.

7. POLLINATION TESTS WITH BLENHEIM AND STARK

(*a*) THE PROBLEM

Of all the varieties grown in the Annapolis valley, the most frequent complaints of lack of fruitfulness are heard regarding Blenheim and Stark. The complaint regarding Blenheim comes mainly from Kings county where many growers report unsatisfactory yields. Attempts to correlate this failure with cultural or nutritional factors, gave inconclusive results. The type of soil was thought to have an influence, since in some cases plantings on the same farm on light and on heavy soil, seemed to favour the latter, but important exceptions were noted. The greatest trouble appeared to exist where large blocks were planted together or where there were indications that cross-unfruitful varieties might be responsible. In some cases where satisfactory crops were obtained, it appeared to be generally true that they were mixed with other varieties, but under very similar conditions other trees did not bear. In one orchard where Cox Orange had been grafted into the tops of the trees no benefit resulted.

Many hand pollinations were made on individual limbs on such non-bearing trees, and in all cases the results were striking and even spectacular where diploids were used as male parents. In one orchard at Lakeville in 1929, limbs crossed with Cox Orange gave a percentage fruit of 23, 20, 36, 28 and 21 respectively, as compared with 2·25, 1·09, 0·44 and 0 when selfed, and 1·3, 2·52, 0·55, 0·52 and 2·09 when open pollinated. Many similar results were secured. From these it would seem that pollination might be a factor, though it did not appear to be the sole factor in all cases.

Complaints regarding Stark were only less frequent than those regarding Blenheim and the trouble appeared to be even more widespread. In the case of Stark the chief complaint was of its erratic and unreliable bearing habits. As with Blenheim the most trouble came from solid plantings of the variety, or when it was mixed with triploid sorts. Hand pollination tests with cross-fruitful varieties gave similar though perhaps, less spectacular results than in the case of Blenheim. There likewise seemed to be an indication that lack of pollination might be responsible for at least a great deal of the trouble with this variety.

It was therefore decided to make extensive tests using a large number of varieties, mainly to determine what were the most effective pollinizers for these two varieties. The results of 1928-1930, which were obtained by the spur unit method, were averaged with those of the year 1931, in which the limb unit method was used.

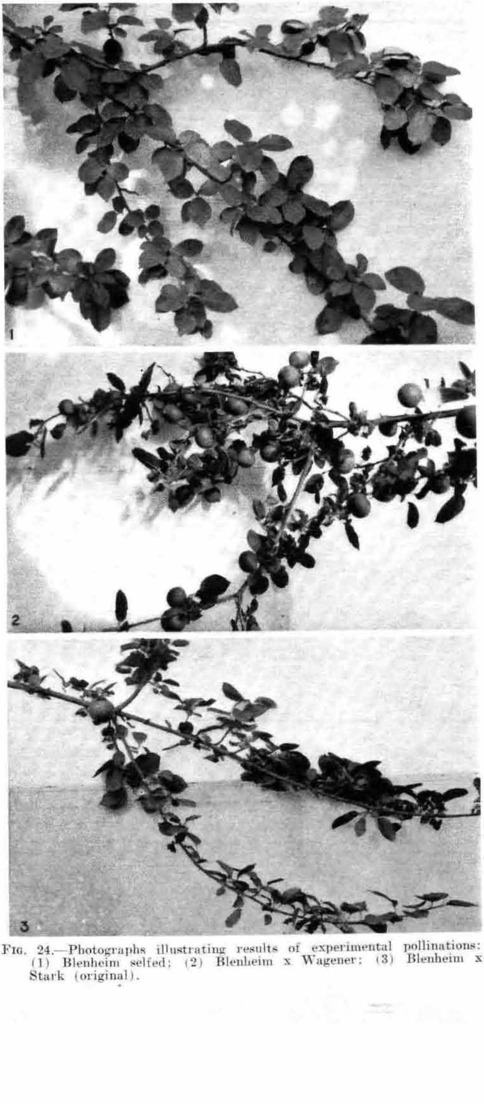


FIG. 24.—Photographs illustrating results of experimental pollinations: (1) Blenheim selfed; (2) Blenheim x Wagener; (3) Blenheim x Stark (original).

(b) BLENHEIM

(i) *Results of Other Workers.*—Little information appears to be available regarding this variety. It has been recorded as self-unfruitful by Harper (1921) and as partially self-fruitful, yielding 0·93 per cent fruit when selfed, by Crane and Lawrence (1929). The latter authors classify this variety as a triploid.

(ii) *Results of Selfing Tests on Blenheim (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
5,279	124	2·35	49	0·93

The results of selfing tests at Kentville over the 1928-1932 period, show a percentage "set" of 2·35 and a percentage "fruit" of 0·93, indicating definite self-unfruitfulness. In 1931, the average per cent "fruit" on the selfed limbs was 5·23, which is a remarkable increase and further illustrates the fact that self-fruitfulness is not a fixed character, but varies with the factors affecting fruit-bud formation, spur vigour, pollen germination, pollen tube growth and possibly other factors. On the whole, it would appear that this variety is one of the most self-unfruitful sorts, and good results should not be expected in ordinary seasons from planting solid blocks of this variety.

(iii) *Results of Blenheim as Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
30,255	5,788	19·13	2,573	8·50

Our figures represent a very large total of blossoms, viz., 30,255, used in crossing tests with this variety and with many different male parents. The majority of these, however, were selected on the basis of their high pollen germination, as reported by other workers, and uniformly good results might, on the basis of results of other work, be expected. The foregoing tests, over a five-year period, gave a percentage "set" of 19·13 and a percentage "fruit" of 8·50, which indicates that Blenheim is very fruitful as a female parent, when effective pollinizers are used. The open pollinated trees (three-year average 1930-1932) gave a percentage "fruit" of 7·92 for this variety, which shows clearly that the value indicated may be a little higher than average.

(iv) *Results of Blenheim as Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent see
2,808	259	9·22	82	2·92	19·25

Our figures for this variety as a male parent are based only on 2,808 bl soms, and confined to tests on Stark. The above tests show a percenta "fruit" of 2·92, and "set" of 9·22, which is lower than Stark selfed, indicat cross-unfruitfulness and may be taken as indicative of its low value as a m parent, a fact that is substantiated by other tests.

(v) *Summary of Results of All Varieties on Blenheim (1928-1932).*

Male Parent	Total blossoms	Per cent set	Per cent fruit
Baldwin	371	10·78	5·12
Ben Davis	566	27·56	12·90
Bishop Pippin	431	33·64	11·37
Bough Sweet	101	2·97	1·98
Cox Orange	4,280	24·69	13·69
Crimson Beauty	220	15·91	7·73
Delicious	993	25·28	13·09
Duchess	614	28·34	12·38
Fallawater	375	6·93	4·00
Fameuse	344	19·48	8·43
Golden Russet	2,000	26·30	13·85
Gravenstein	2,345	10·70	3·88
Grimes Golden	323	26·32	9·60
Hubbardston	366	16·12	7·65
Jonathan	885	20·90	5·88
King	2,437	4·60	2·42
McIntosh	895	19·66	8·16
Melba	634	21·61	8·20
Nonpareil	491	6·31	2·85
Ontario	441	26·30	14·97
Red Astrachan	637	24·18	9·11
R. I. Greening	405	8·15	5·19
Ribston	541	9·61	4·25
Rome Beauty	127	71·65	10·24
Spy	144	22·92	6·94
Stark	1,900	4·42	2·58
Stayman Winesap	630	11·75	5·08
Wagener	2,783	20·01	8·08
Wealthy	1,302	15·75	4·84
Wellington	326	34·66	18·40
Winter Banana	343	29·15	10·20
Wolf River	597	29·98	10·72
Yellow Transparent	1,040	35·48	10·48
York Imperial	440	29·55	18·64

It is hardly necessary to point out that where crosses represent a very small blossom population, irregularities due to limb vigour, pollen germination, etc., greatly increase the probability of error in the results.

(vi) *Other Data.*—As already indicated, data from commercial orchards and hand pollination tests seem to show that, where effectively pollinated, Blenheim is capable of producing good crops, though it would seem that some other factor must be involved in at least some cases of non-bearing, or that the variety experiences more difficulty in becoming cross-pollinated than many others. Its pollen has a low value for crossing purposes and its self-unfruitfulness is most pronounced. In 1931 it gave a high percentage " fruit " in selfing tests and this coincided with a heavy yield of Blenheims all over the valley. Many, though not all, plantings that had yielded poor crops before, gave good yields in 1931. Nothing could better illustrate the variable character of the factor of self-fruitfulness.

This point is well illustrated by an experiment conducted at Waterville. There was a block of Blenheim that the owner in 1919 decided to graft into Cox Orange, but only the tops of the trees were completed. The Cox Orange came into bearing in a few years and bore satisfactory crops, but there was no benefit to the Blenheims, which continued to bear little or nothing.

In 1931, one of these trees was tented and a hive of bees introduced. The set of fruit obtained was very high, viz., 13·72 per cent, but the open pollinated trees yielded 9·83 per cent, which is also very high and the difference between the two is not particularly significant. Any other year the results might have been very different, and the danger of drawing conclusions from one year's results is thereby emphasized.

An interesting result obtained in this experiment is the low percentage fruit produced by the Cox Orange limbs inside the tent, as a result of selfing or Blenheim crosses, as compared with the much higher percentage fruit on open pollinated limbs, where cross-fruitful pollen was evidently available. Table No. 10 gives the results.

TABLE No. 10.—TABLE SHOWING FRUIT, ETC., ON TENTED AND UNTENTED BLENHEIM—COX ORANGE TREES

Location of station	Variety	Number blooming spurs counted	Average number blossoms per blooming spur	Per cent fruit to bloom
In tent	Blenheim	502	4·85	13·72
In tent	Cox Orange	501	4·00	4·71
Outside tent	Blenheim	720	5·18	10·97
Outside tent	Cox Orange	516	4·29	9·83

NOTE: These trees were Blenheim with top of tree top-worked to Cox Orange.

(vii) *General Summary for Variety.*—Blenheim under most conditions is highly self-unfruitful, but may occasionally give reasonable yields even when selfed. It is very fruitful as a female parent when pollinated with an effective pollinizer, but is a particularly poor male parent.

(c) STARK

(i) *Results of Other Workers.*—Very little information is forthcoming as to the fruiting habits of Stark. Ballard (1914) reports no set when pollinated with Red Astrachan in Maryland. As a male parent it is reported to have given 3·5 per cent fruit on Northern Spy, by Marshall, Johnston, *et al.* (1929); no set is reported as having been obtained when used on McIntosh in Washington by Morris (1920) and the same result was obtained by Ballard (1916) on Yellow Transparent.

(ii) *Results of Selfing Tests on Stark (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
3,073	280	9·11	106	3·45

Hand pollination tests at Kentville indicate a degree of self-fruitfulness for the variety, viz., 9·11 per cent "set" and 3·45 "fruit". However, the latter figure may not be considered sufficiently high to produce a commercial crop for this variety, and the planting of solid blocks should be avoided. The open pollinated trees over a three-year average (1930-1932), gave a percentage fruit of 7·73, which may be considered a good commercial crop for the variety.

(iii) *Results of Stark as a Female Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
27,234	9,453	34·71	2·154	7·91

Stark, from our results, may be termed a good female parent, a percentage "set" of 34·71 and "fruit" 7·91 being obtained over a five-year average (1928-1932). Our figures represent the massed results of some thirty-five male parents

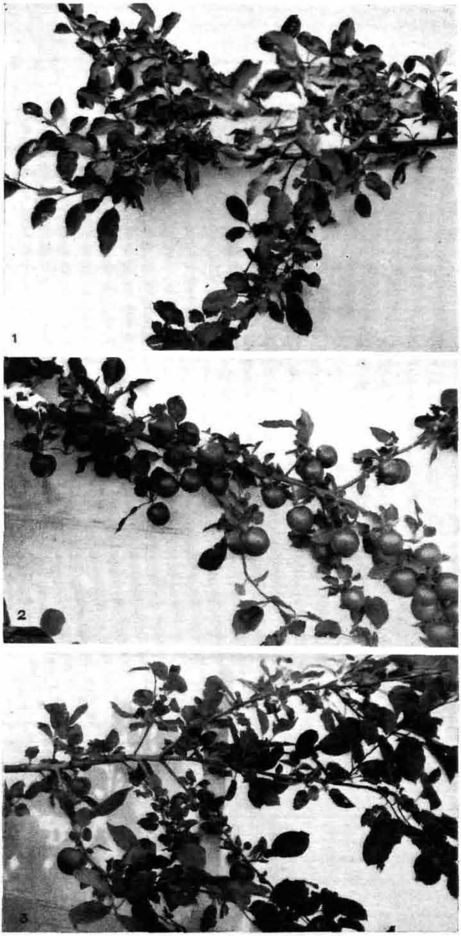


FIG. 25.—Photographs illustrating results of experimental pollinations: (1) Stark selfed; (2) Stark x Wagener; (3) Stark x Gravenstein (original).

on this variety, the larger number of which were selected because of their high pollen germination ability, and a fairly high percentage "fruit" might be expected. Its value as a *female* parent in these tests, however, is only slightly higher than that of the open pollinated trees and indicates that the variety is fruitful when effectively pollinated.

(iv) *Results of Stark as a Male Parent (1928-1932).*

Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Per cent seeds
1,900	84	4·42	49	2·58	14·73

As a male parent, Stark has given inferior results, being similar to Blenheim in this respect. The tests over the five-year period show a percentage "set" of 4·42 and "fruit" 2·58.

(v) *Summary of Results of All Varieties on Stark (1928-1932).*

Male Parent	Total blossoms	Per cent set	Per cent fruit
Baldwin	603	23·38	4·64
Ben Davis	410	59·76	13·17
Bishop Pippin	537	60·71	6·15
Blenheim	2,808	9·22	2·92
Bough Sweet	86	10·47	8·14
Cox Orange	2,451	33·66	9·83
Crimson Beauty	630	42·86	9·52
Delicious	672	70·39	7·89
Duchess	638	36·36	7·84
Fallawater	530	20·00	7·36
Fameuse	414	53·38	8·94
Golden Russet	2,164	36·88	11·88
Gravenstein	2,062	14·35	5·63
Grimes Golden	663	41·78	5·13
Hubbardston	241	52·28	7·05
Jonathan	791	60·18	8·47
King	2,547	22·26	6·60
McIntosh	670	67·31	12·24
Melba	199	57·79	4·02
Nonpareil	407	23·34	7·62
Ontario	213	67·14	7·04
Red Astrachan	523	49·33	10·71
R. I. Greening	337	28·49	7·41
Ribston	568	19·54	8·6[illegible]
Rome Beauty	154	81·82	7·1[illegible]
Spy	229	55·90	10·9[illegible]
Stayman Winesap	488	7·79	2·4[illegible]
Wagener	2,221	40·84	11·3[illegible]
Wealthy	717	37·80	6·1[illegible]
Wellington	255	59·61	10·2[illegible]
Winter Banana	383	50·91	8·0[illegible]
Wolf River	610	59·34	15·[illegible]
Yellow Transparent	536	5·04	1·[illegible]
York Imperial	477	69·39	8·[illegible]

(vi) *General Summary for Variety.*—Starks are more self-fruitful tha Blenheims, but not to the extent of yielding commercial crops when planted i solid blocks. They are very fruitful when pollinated with diploids and give low percentage "fruit" when used as male parents.

TABLE No. 11.—THE FRUITFULNESS OF DIFFERENT TYPES OF BLENHEIM AND STARK CROSSES (1928-1932)

Cross	Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit	Seeds*	
						Per cent	Average number per apple
Bleinheim x Diploids	15,141	3,623	23·93	1,689	11·16	36·47	4·56
Blenheim x Triploids	8,490	603	7·10	276	3·25	9·31	3·41
Blenheim x Others	6,624	1,562	23·58	608	9·18	35·06	4·47
Blenheim Selfed	5,279	124	2·35	49	0·93	2·66	2·73
Stark x Diploids	11,599	5,183	44·68	1,173	10·11	37·18	4·23
Stark x Triploids	9,332	1,565	16·77	499	5·35	10·38	2·76
Stark x Others	6,303	2,705	42·92	482	7·64	23·56	3·44
Stark Selfed	3,073	280	9·11	106	3·45	6·80	2·90

* Seed counts made on basis of actual number of fruit harvested.

(*d*) GENERAL RESULTS AND CONCLUSIONS

1. The general results obtained by the various tests on Blenheim and Stark lead to general conclusions similar to those obtained with standard varieties. The behaviour of the two varieties, both triploids, is very similar. Stark is, however, more self-fruitful than Blenheim. Both varieties are fruitful when pollinated by diploid varieties and both give inferior results as male parents on all varieties tested.

2. Blenheim is ordinarily one of the most self-unfruitful varieties grown in the Province, giving an average of 0·93 per cent over a five-year period when self-pollinated. The fact that self-fruitfulness is not a fixed character is, however, well exemplified in our studies of this variety, which in 1931 gave a percentage " fruit " of 5·23 when selfed. Stark gives more uniform results over this period with an average of 3·45 per cent in selfing tests.

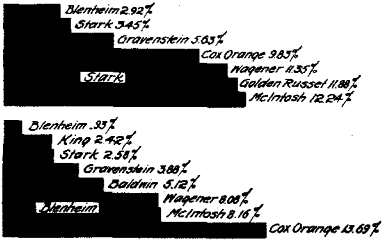


FIG. 26.—Effect of various male parents on Stark and Blenheim—per cent of fruit after July drop (average for five years, 1928-32) (original).

3. Both varieties appear to require greater provision for suitable cross-pollination than most others and this fact must be taken into account in all new plantings or in grafting-out operations. Furthermore, wherever these varieties occur in mixed plantings the fact that both give very inferior results as male parents, even to the extent of inhibiting selfing in some cases (see results of tent experiments), must also be recognized.

4. Among commercial varieties, the early blossoming sorts such as Wagener and Golden Russet are excellent pollen parents for both varieties. Cox Orange gives good results in hand pollinations, but, if depended upon exclusively, it may be somewhat late in blossoming in some seasons. The value of these male parents is indicated in the seed counts, as was found to be the case with the standard varieties.

5. Detailed results are presented in the accompanying table and chart.

8. PLANNING THE ORCHARD

In considering the question of setting out new orchards or grafting our old ones several points require consideration:

1. The planting of blocks of self-unfruitful varieties, which includes all the varieties listed by us except Baldwin, should be avoided.

2. The proper admixture of cross-fruitful varieties, of which the bloom overlaps sufficiently to permit cross-pollination, should be given consideration.

3. If the bloom does not exactly coincide, it is preferable for that of the variety introduced as a pollinizer to be a little earlier rather than a little later than that of the variety it is desired to pollinate.

4. The varieties used as pollinizers must themselves be provided with pollinizers, as many varieties that produce excellent pollen for crossing purposes are themselves quite self-unfruitful.

The best supply of pollen is that provided by effective pollinizers planted at suitable intervals in the orchard. Authorities differ as to how many are required, some advising at least every fourth tree in every fourth row, others claiming that a full row of the pollinizer every second or third row is not too great. It is difficult to give definite recommendations from the evidence available, especially when the effect of over-pollination is considered, but, from a study of all the factors involved it would appear that the provision of a full row every fourth row would represent the minimum provision for pollination where only diploid varieties such as Golden Russet, Wagener, Cox Orange or Northern Spy occur in the block concerned. The evidence at hand indicates that in certain seasons pollination is very local and that, in order to provide against such conditions, even closer planting than that indicated would be advantageous. The need for special provision of abundant pollinizers is most acute in the case of such varieties as Blenheim and Stark, and is of importance wherever triploid varieties form a large proportion of the planting. Full rows seem to be preferable to scattered trees under these conditions. The habit of bees of working a limited locality is an important consideration.

The blossoming period of Gravenstein and King, for example, sufficiently overlaps that of Golden Russet or Wagener to enable the former to be pollinated by the latter, but neither King nor Gravenstein will give best results as pollinizers for other varieties. Gravenstein, however, is superior to King in this respect. Golden Russet and Wagener are inter-fruitful, and are sufficiently overlapped by Cox Orange to give fairly satisfactory results. Cox Orange is also an excellent pollinizer for Baldwin, and Golden Russet also overlaps sufficiently to be of service, especially to the earlier bloom. Spy presents the greatest problem of our commercial sorts. Cox Orange overlaps to a sufficient extent in most years to give a good crop, but in seasons where the bloom is more prolonged Ben Davis gives better results. However, Ben Davis is no longer recommended for new plantings. Rome Beauty has given good results elsewhere, but there appears to be some difference of opinion as to the commercial value of Rome Beauty in the Valley, owing mainly to the poor growth habits of the tree. In a season like 1930 when the bloom came and went practically within a week, there is not the same problem as regards overlapping of bloom, but in some seasons the unevenness of bloom of the different varieties constitutes a difficulty.

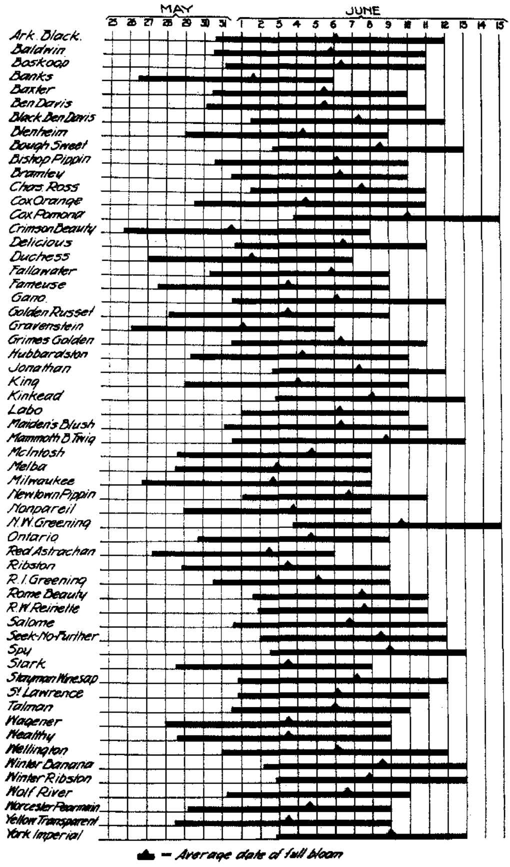


FIG. 27.—Chart showing average blooming period of different varieties (1924-31) (original).

However, Cox Orange can be depended upon to give at least fair results on Spy, and owing to the fact that this variety blossoms very unevenly, it is suitable for pollinating a wider range of varieties than almost any other. When the pollen of Golden Russet or Wagener is dried and properly stored it gives excellent results on Spy, but under orchard conditions the difference in the blooming period is too great to make them dependable pollinizers for the latter variety. If McIntosh is used, it works well with the medium blooming varieties, including Golden Russet.

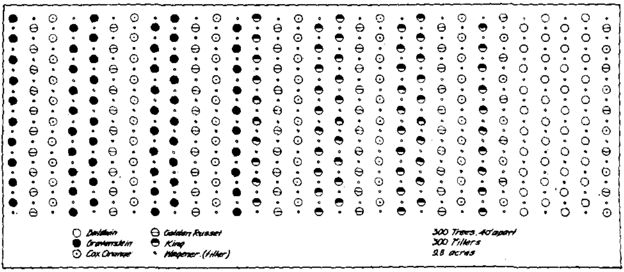


FIG. 28.—Suggested plan for a five-variety orchard with fillers (original).

For Blenheim, Golden Russet and Wagener provide suitable pollinizers and McIntosh works fairly well. Cox Orange, in some seasons, is late for best results. The same varieties are satisfactory for Stark. In providing pollinizers for Blenheim and Stark it would seem to be advisable to do so in greater abundance than for the standard varieties, in order to make pollination more certain. It is suggested, in setting out poor pollen-producing varieties, that not more than two rows be placed together, followed by a row or two of a pollinizing variety, which, in turn, should be followed by one or two rows of a variety cross-fruitful with the latter. Whether one or two rows would be used would

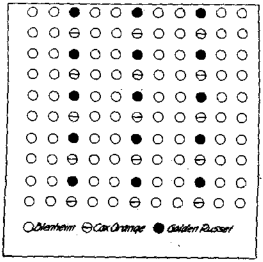


FIG. 29.—Possible plan for top-working solid block of Blenheim to give minimum number of pollinizers. Golden Russet used to pollinate Blenheim and Cox Orange to pollinate Golden Russet (original).

depend upon the proportion of each that it is desired to have in the orchard. Where it is necessary to top-work a block of a self-unfruitful variety, such as Blenheim, for the purpose of improving the set, every third row should be worked over, one half with a variety introduced primarily to pollinate Blenheim and one half with a variety introduced primarily to pollinate the pollinizer of the Blenheim. In introducing varieties for pollinizing purposes, the most desirable commercial sorts should be selected.

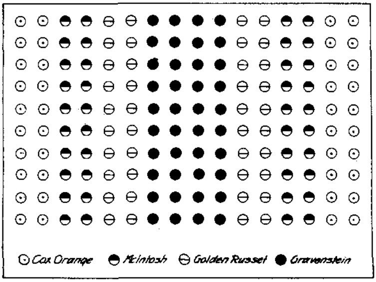


FIG. 30.—Suggested plan for a four-variety orchard (orginal).

The accompanying charts showing (1) average blossoming periods of varieties (2) the cross-fruitfulness of varieties and (3) typical combinations of varieties, will illustrate the application of the results of the foregoing investigations.

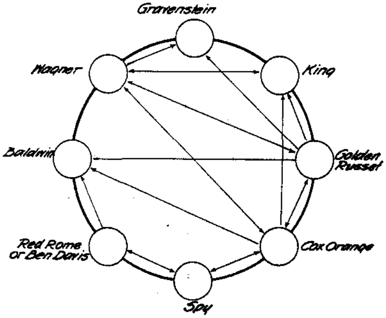


FIG. 31.—Chart showing inter-fruitfulness of some standard varieties. Arrows indicate direction of cross (original).

Ben Davis is added, though not a recommended variety, because of abundance in commercial planting and superior results on Northern Spy.

9. RELATION OF FRUIT SET ON ENTIRE TREE TO THAT ON INDIVIDUAL LIMBS OR SPURS

It has already been indicated elsewhere that where the whole tree is exposed to effective cross-pollination, individually pollinated limbs give lower yields than when the remainder of the tree is ineffectively pollinated or not pollinated at all.

This is most clearly brought out in tented trees of such self-unfruitful varieties as Gravenstein and Spy. The figures in the accompanying table show that, as a rule, the lower the set on the tree, the higher the set on the individual limb pollinated, and *vice versa*, though not, of course, in direct proportion.

TABLE No. 12.—EFFECT OF NUTRITIONAL COMPETITION ON TENTED TREES (1928-32)

Variety	Treatment	Whole trees		Limb hand pollinated with an effective pollinizer	
		Per cent set	Per cent fruit	Per cent set	Per cent fruit
Gravenstein	No bees and no bouquets	0·90	0·67	70·66	47·11
"	Bees and effective bouquets	21·18	10·90	34·80	18·38
King	No bees and no bouquets	4·13	1·03	37·63	11·87
"	Bees and effective bouquets	30·11	5·42	29·28	7·32
Baldwin	No bees and no bouquets	8·23	3·49	43·05	19·15
"	Bees and effective bouquets	31·11	8·17	45·41	12·69
Spy	No bees and no bouquets	1·09	0·85	66·90	26·34
"	Bees and effective bouquets	49·21	10·05	83·09	18·18

10. OVER-POLLINATION

MacDaniels (1931) has emphasized the factor of over-pollination in connection with biennial bearing. It was noted in our tented series, especially in the Gravenstein variety, that trees supplied with bees and an effective pollinizer and yielding heavy crops, failed to give a crop the following year. On the other hand where blossoming trees were prevented from bearing through lack of insect pollinators, there was a strong tendency to bear abnormally large crops the following year. In other words, what amounted to defloration took place. Where bees and ineffective bouquets were used in tented series, and only a small crop resulted, the trees in the following years tended to approach an annual habit. The above data tend to indicate that the amount of pollination that occurs in any given year has an influence on succeeding crops.

Baldwin is the one variety under test that is most outstanding in its biennial bearing habit in the Valley orchards, a high percentage of spurs blossoming each year. It is also our most self-fruitful variety. It is a well known fact that, when Baldwin blossoms it, unlike some other varieties, almost invariably fruits. Pollination of this variety is seldom lacking owing to its self-fruitful habits. With little cross-pollination, it tends to bear heavy crops, so as usually to require thinning. This is ordinarily followed by a pronounced " off year ".

At the opposite extreme is the King variety, which, in our tests, rarely gave a large percentage of fruit from a given number of blossoms. Even where the original set was heavy, abscission was correspondingly heavy, so that there was less difference than is ordinarily the case between selfing, good pollinizers and poor pollinizers. Coincident with this we have the annual bearing habit more pronounced in this variety in the average Valley orchard.

11. TEMPORARY PROVISION OF POLLEN

(a) POLLINIZING BOUQUETS

As a temporary means of supplying suitable pollen, before grafting operations can become effective, the use of bouquets has been advocated. These consist of blossoming limbs of the desired varieties placed in tubs of water in the orchard or hung in the branches. Results from such methods are apt to be disappointing, as indicated elsewhere. It is difficult to furnish a sufficient mass of bloom to be effective over the much greater proportion of ineffective pollen present. It also is difficult to keep such bloom fresh or in good condition, especially in hot dry weather. Bouquets are ordinarily not as freely visited by bees as the greater masses of bloom provided by whole trees and, if allowed to wilt, may become quite unattractive. Furthermore, it is a method that is not generally popular with growers.

(b) HAND POLLINATION

As an alternative to the temporary use of bouquets, MacDaniels (1930) has suggested the hand pollination of the orchard. He claims that, hand pollination of apples when the weather is unfavourable for natural cross-pollination gives very successful results, the blossoms to be picked just before opening, the unopened anthers pulled off and spread on paper trays in a warm room to dry; the pollen should then be placed in small unstoppered bottles and applied to the trees with a camel's hair brush as soon as possible. On a heavy blossoming tree he states that it would only be necessary to pollinate 20 to 25 per cent of the blossoming spurs to get a full crop, nor should all the flowers in a cluster be treated. With experience it is said that a tree 15 years old capable of bearing 10-15 bushels can be pollinated in an hour and a half. Another method described is to cut branches of a good pollinizing variety when pollen is being shed and to brush the mother trees with these.

(c) THE "BEE POLLEN-COATER"

Yet another method of furnishing a temporary supply of pollen has been experimented with by Burrell and King (1931) and consists of a device known as a "pollen-coater". Its purpose is to force the bees to walk through a quantity of pollen on entering or leaving the hive.

The bee pollen-coater is a modification of what is known to beekeepers as a winter hive entrance block. The latter is essentially a diagonal horizontal tunnel about 6 inches long, 3 inches wide and ½-inch high, attached to the front of the hive. Its ordinary use is to permit free passage of the bees in and out of the hive at will, but at the same time, to check air currents that would chill the colony.

For the present purpose the roof of the tunnel is removed. Two wooden strips each ¼-inch high are nailed across the floor of the tunnel, thus forming an enclosure to contain the pollen. A glass plate is substituted for the original roof of the tunnel so that one may observe the bees and determine readily when the pollen supply needs replenishment. A piece of wood is laid on the glass plate in sunny weather to prevent excessive heating of the pollen. The workers referred to above consider that this device holds promise of successfully solving the problem of pollen distribution in the absence of suitable pollinizers in the orchard.

(d) USE OF ORCHARD DUSTER WITH BOUQUETS

Still another method has been tried by us with good results during the season of 1932, and it has much to commend it over either hand pollination or the use of bouquets. It consisted in placing a bouquet of a cross-fruitful variety adjacent to the tree to be pollinated, and blowing through it a current of air from an ordinary orchard duster. The work must be done very thoroughly and

the draft directed through the bouquet in all directions. Provided the anthers are in the proper condition the pollen may be blown right out of the anthers and results obtained similar to those secured in hand pollinations. The results as set forth in the accompanying table may be compared with those from the tented series or with those secured through hand pollinations. The air velocity obtained at different distances from the outlet is given in another table.

TABLE No. 13.—RESULTS OF TESTS IN FORCED DRAFT POLLINATION, 1932

Variety	Total blossoms	Total set	Per cent set	Total fruit	Per cent fruit
Gravenstein	2,540	95	3·74	86	3·39
King	1,841	399	21·67	132	7·17
Baldwin	2,411	472	19·58	242	10·04
Spy	2,792	340	12·18	198	7·09

The foregoing results indicate clearly that effective pollination can be effected by this method. In the Gravenstein tent Wagener bouquets were used, and the increase over that of the selfed tree was three per cent. Wagener bouquets were again introduced into the King tent and here we find an increase of four per cent over that of selfing, which is very significant, especially in the case of such a variety as King. Cox Orange was used as bouquets for the Baldwin tree and Ben Davis for the Spy, and again a gain of three and two per cent respectively, over that of corresponding selfed trees was obtained. Its use from a practical standpoint is questionable, but it certainly offers a means by which a fruit grower can increase yields, where blocks of self- or cross-unfruitful varieties occur and it requires less detailed work than hand pollination.

It may be noted that the open pollinated trees in the same set of tests, proved only slightly better in the case of each variety.

Table 13 (a) showing the velocity of the wind inside and outside the tent is given for purposes of record and because of its bearing on wind pollination on tented trees. Considerable irregularity is noted, but the difference between tented and untented trees is very apparent.

The measured air velocity at different distances from the mouth of the pipe is given in table 14.

TABLE No. 13 (*a*)—COMPARISON OF WIND VELOCITY INSIDE AND OUTSIDE TENT, WOLFVILLE, N.S.

Date	Time	Wind in feet per minute		Date	Time	Wind in feet per minute	
		In tent	Outside tent			In tent	Outside tent
Sept. 2	2·30	4·6	179·0	Sept. 7	2·45	22·8	317·0
	2·35	1·6	42·3		2·50	2·6	497·0
	2·40	2·4	253·5		2·55	11·2	95·0
	3·30	0	74·0		3·15	14·0	264·0
	3·35	0	15·8		3·20	3·6	116·0
	3·40	0	42·3		3·25	0·8	179·0
Sept. 5	4·45	0	137·2		3·45	0·4	232·0
	4·50	0	95·0		3·50	10·2	190·0
	4·55	0	102·0		3·55	18·8	273·0
	5·00	0	127·0		4·15	2·2	157·0
	5·05	0	127·0		4·20	0·4	157·0
	5·10	0	179·0		4·25	1·2	52·8
Sept. 6	9·30	2·8	338·0		4·45	1·4	52·8
	9·35	9·6	317·0		4·50	0·6	126·8
	9·40	0	158·5		4·55	0·6	105·5
	9·45	33·6	190·0	Sept. 9	2·00	107·6	410·2
	9·50	57·4	433·0		2·05	80·0	422·0
	9·55	28·6	102·0		2·10	142·4	455·0
	10·15	10·8	179·0		3·00	101·8	380·5
	10·20	1·0	214·3		3·05	97·4	296·0
	10·25	2·4	296·0		3·10	80·0	322·0
	2·50	12·4	179·0		3·30	170·5	518·0
	2·55	25·0	243·0		3·35	142·0	423·0
	3·00	17·0	296·0		3·40	184·1	465·0
	3·35	49·0	317·0		4·00	211·6	475·0
	3·40	47·4	357·0		4·05	215·0	581·0
	3·45	43·2	348·0		4·10	201·8	518·0
	4·35	19·4	264·0		4·30	189·0	496·0
	4·40	1·8	116·0		4·35	163·6	538·0
	4·45	24·2	158·0		4·40	126·0	581·0

TABLE No. 14.—VELOCITY OF CURRENT FROM ORCHARD DUSTER IN RELATION TO DISTANCE FROM MOUTH OF PIPE

Distance from mouth of pipe	M.P.H.	Distance from mouth of pipe	M.P.H.
½'	77·86	9	11·98
1	63·12	10	10·82
2	48·30	11	9·85
3	36·42	12	9·04
4	26·55	13	8·39
5	21·41	14	7·81
6	18·41	15	7·36
7	15·74	16	6·98
8	13·68		

12. INHIBITING EFFECT OF UNFRUITFUL POLLEN

In some cases, though not in all, there is an indication that pollen from a cross-unfruitful variety actually inhibits selfing. This may be true even in varieties that normally give very little fruit when selfed, but more particularly in a comparatively self-fruitful variety such as Baldwin.

Several examples of the foregoing may be cited. On Gravenstein tented trees supplied with bees and bouquets of an ineffective pollinizer, viz., Blenheim, over a four-year period gave an average percentage "fruit" of 1·14, and the tented selfed Gravenstein trees (bees and no bouquets), gave 2·12 per cent "fruit" over the same period, in other words an inhibiting effect of nearly 1· per cent. Baldwin, tented trees supplied with bees and ineffective bouquets (Nonpareil) yielded an average percentage "fruit" of 4·96. The same variety

when selfed (*i.e.* bees and no bouquets) produced 7·77 per cent "fruit," *i.e.* a decrease of nearly three per cent fruit, which means the difference between a good and a fair commercial crop.

13. VARIATION IN SELF-FRUITFULNESS

(*a*) SEASONAL

Self-fruitfulness in the apple appears to be influenced by the climatic conditions especially during its period of stigma receptivity. This fact is well established in our selfing records throughout the period of our studies. One striking example of this variation became evident in 1932. Spy in the tented series showed an average percentage "fruit" of ·93 on selfed trees (*i.e.* bees and no bouquets) during the 1929-1931 period, which strongly indicates self-unfruitfulness. However, in the season of 1932 the tented selfed tree gave a percentage "fruit" of 4·84, or in other words, a commercial crop was produced by selfing. In 1932, the selfed limbs in the hand pollinated tests on Gravenstein showed a percentage "fruit" of 2·79, this figure being 1·64 per cent higher than the five-year average. On the other hand selfing tests on Baldwin in 1932 gave a percentage "fruit" of 3·01, which was 3·36 per cent less than the five-year average and a low percentage fruit for such a comparatively self-fruitful variety. In 1930, the latter variety showed a percentage "fruit" of 9·50 on the hand selfed limbs.

Hand pollination tests in 1932 indicate that King is very self-fruitful, a percentage "fruit" of 6·11 being obtained. The average for the five-year period was 3·56. All data cited indicate clearly that there is a wide fluctuation in self-fruitfulness from year to year, and a true value for any one variety can only be obtained over a period of years. These differences are usually attributed to "climate," though it is not always possible to state what particular item or items in the complex are responsible.

(*b*) DUE TO TECHNIQUE

Self-fruitfulness in apples varies in relation to the experimental technique used as is clearly portrayed in the accompanying table. The bagged series includes the limbs self-pollinated by hand under cheesecloth bags. The tented series is made up, first, of those limbs self-pollinated by hand under cheesecloth bags within the tent and, second, of the whole tree, exclusive of the individual limb, selfed by bees and enclosed in a cheesecloth tent. All varieties when self-pollinated by bees under tents, showed a higher degree of self-fruitfulness than where selfed by hand on the same tree. The hand self-pollinated limbs under cheesecloth bags in the open, gave uniformly higher percentages than those hand selfed within the tents. On the other hand, selfed limbs under cheesecloth bags in the open gave, in every variety except King, slightly lower percentages than those selfed by bees in the tents. In the case of King the percentages were practically the same.

TABLE NO. 15

Variety	Bagged series 1928-1932	Tented series, 1929-1932	
	Selfed by hand	Selfed by hand	Selfed by bees
Baldwin	6·37	2·22	7·
Gravenstein	1·15	0·59	2·
King	3·56	2·55	3·
Spy	1·33	0·73	2·

The necessity of taking into account the technique used by various worke [illegible] their results, is very plainly indicated by the foregoing.

IV. FIELD STUDIES IN THE ROLE OF INSECTS IN APPLE POLLINATION

W. H. BRITTAIN

A. INTRODUCTION

The following studies were conducted as a part of the general investigation of apple pollination in the Annapolis valley, Nova Scotia. In view of the efforts that have been and are being expended by various extension organizations with a view to increasing the use of hive bees as orchard pollinators, and in view of the absence of any adequate supply of hive bees in the territory concerned, it seemed advisable to make a careful study, not only of the role of hive bees in orchard pollination, but also of the native insect fauna to which most of the pollination that actually takes place must be due. In this connection, it was thought best to conduct our studies from the comparative standpoint, using the hive bee as the standard of comparison, since the behaviour of this species has been much more fully studied. The main object of these studies was to determine the abundance and distribution of the wild bee fauna, their relative value as pollinators as compared with hive bees, the necessity or otherwise of supplementing their activities by introducing hive bees and the problems connected therewith. Though considerable information has been accumulated, much still remains to be accomplished before all the points dealt with are finally elucidated.

Throughout the course of these studies the writer has received continuous assistance from Mr. J. M. Cameron, not only in carrying out the experimental work in the field, but in tabulating and analyzing the data secured. Mr. C. B. Gooderham, who appears as joint author of one section of this report, has contributed invaluable assistance in very many ways. Mr. C. E. Atwood has taken part in the field studies at various times. Mr. John Leefe also performed useful service during the season of 1932.

B. GENERAL

The apple depends almost entirely upon insects for pollination. While our experiments show that a certain amount of pollen may be carried by wind, our results are in agreement with other workers, who find that wind pollination is negligible in apple pollination. The fact must not be lost sight of that a suitable pollen supply is of equal importance to the work of bees in order to insure proper pollination, since, without effective pollinizers, the activities of bees would result only in selfing, or in unfruitful crosses. This fact is emphasized because it has been the practice of a number of growers, when confronted with a pollination problem, to endeavour to remedy the situation by introducing bees into the orchard, disregarding the primary necessity of ensuring a proper pollen supply.

C. INSECTS CONCERNED

1. HISTORICAL

Many workers have studied the role of insects in the pollination of apples and a great deal of valuable information is available as a result of these studies. Some of the more recent studies are worthy of consideration at this point. Among those who have paid attention to the insect visitors of apple bloom, the observations of Britton and Viereck (1906) are of interest.

These authors quote several writers who have found that honey bees are the most important insects engaged in pollinating fruit flowers, but their own findings are to the contrary, as honey bees were exceedingly scarce in comparison with other insects. Their observations were made at New Haven and Branford, where bee hives were less than two miles away, and wild honey bees present. Two hundred and twenty-nine insects of 52 species were collected from the apple. These included 9 species of *Halictus*; 5 species of *Andrena*; 3 of *Trachandrena*; 4 of *Bombus*; and *Apis mellifica*; besides other bees and wasps—in all, 32 species of Hymenoptera. *Osmia lignaria* was the commonest single species, 34 individuals being collected out of a total of 197 Hymenoptera; 65 *Halicitus*, 31 *Apis*, and 28 *Andrena* were also taken. *Apis* was comparatively more abundant on apple than on other fruit trees. The authors believe that most Diptera are of no importance as pollinators, although a few may be considered beneficial. They also conclude that on account of their great numbers, the small bees belonging to the Halictidae and Andrenidae were of far greater importance in pollinating the flowers of the plants from which they were taken than were the honey bees, during the seasons of 1905 and 1906.

Rawes and Wilson (1922) have also studied this question and agree with other workers that wind plays no part in the pollination of apple trees. Insects are the only efficient pollinators, and although honey bees are active agents in carrying pollen, this work may be most efficiently performed by other insects. Among insects other than hive bees, bumble bees take the foremost place, and are not kept from their work by dark weather. *Andrena* and allied species are next. *Eristalis, Syrphus* and other small flies are considered to play a considerable part in apple pollination. In regard to apples and pears, hive bees and flies are more frequent visitors than wild bees or other insects.

Observations were made by Hooper (1929 and 1931) over several years on the numbers of various insects visiting apple blossoms, and the numbers added up. The district contained many cherry, apple and other fruit plantations and numbers of hive bees were kept. The land not in orchard was either ploughed land or sheep pasture, not very suitable for pollinating insects. The counts on apple were as follows:

Hive bees	374	Beetles	104
Bumble bees	37	Ants	51
Halicti, etc.	21	Earwigs	3
Flies	23	Thrips	2

Fox-Wilson (1929) has also made a careful study of this question. This author gives a description of Wisley gardens, which are near rough land and pasture. Various factors besides pollination which affect fruit setting are discussed. Most common fruit flowers are shown to be entomophilous. In order to determine the cause of attraction of insects to flowers, some apple blossoms had the petals removed. Hive bees, Syrphids and Anthomyids, visited these blossoms. Bumble bees ignored them. Artificial blossoms without nectar attracted bumble bees, but hive bees ignored them, until nectar was placed in them. Sight is considered more highly developed in *Bombus*, smell in *Apis*.

The various types of pollinating insects were discussed briefly. Honey bees were considered to be the most efficient because of their industrious habits, etc. Bumble bees were less deterred by unfavourable weather than hive bees, and under the conditions occurring in 1920, various wild insects secured a good crop with no hive bees present. Andrenidæ were found very subject to changes in weather. They showed greatest activity from 11 to 1 p.m. and from 2 to 4 p.m., resting from 1 to 2 p.m. Various other Hymenoptera and Diptera were mentioned as visitors to fruit blossoms. Gnats of the family Mycetophilidae were found to surpass all other insect visitors to apple, etc.; but owing to their small size, are usually overlooked. They carry considerable pollen. Coleoptera

were found of practically no use as pollinators, although frequent visitors. The number of visitors to apple during a total period of 40 hours, 45 minutes, comprising observations in 1920, 1921, 1922, 1923 and 1924 is given as follows:—

Hive bees	222	Other Hymenoptera	44
Bumble bees	337	Diptera	488
Wild bees	106	Miscellaneous	132

The author does not state on what quantities of bloom his observations were made.

Hutson (1926) quotes the work of various investigators in regard to insects other than the honey bees concerned in pollination of fruits. Calculations of insects visiting bloom between 12 noon and 1 p.m. for three years are given in this paper. These include Chironomidae, Muscidae, Bombidae, Syrphidae and Scarabaeidae. Honey bees also were found to work differently in different varieties. There was also a variation from year to year, *e.g.*, 9 per minute in 1923 and 6 in 1924, a variation of from 5 to 90 seconds having been observed in length of time spent on apple bloom when collecting nectar. The main point brought out by the collections was the small number of insects found in apples during bloom. There was a marked difference in the numbers found in the one orchard surrounded by tilled land and the planting surrounded by overgrown land, especially in the greater number of bumble bees found in the latter.

A brief discussion of the relative importance of the various groups concerned as determined by our studies follows. Owing to limitations of time, equipment, personnel, and to constant trouble from poisoning, much of the work could not be carried out as origiually conceived and some of our conclusions must be regarded as tentative.

2. HIVE BEES

It may be pointed out at the outset that the question of orchard pollination by hive bees in the Annapolis valley is at present largely an academic one. Due to the widespread effect of poisoning from orchard dusts and sprays, which is discussed in detail elsewhere, the hive bee population, over square miles of the main orchard area is practically nil, and this area must depend upon wild forms for pollination.

In 1931 there was an aggregate of 493 colonies in the whole of Kings county, distributed among 46 owners. Of these 198 were the property of owners who practiced migratory beekeeping; 188 were the property of the Experiment Station and the Pollination Project and used for experimental purposes; and about 25 were in towns or outside the fruit belt, leaving only about 102 colonies to pollinate about 30,000 acres of orchard. Obviously the hive bee at the present time and for several years past has had little influence in fruit pollination in the area studied.

3. BUMBLE BEES

Bumble bees are a variable quantity. They are more numerous in the region of the North Mountain, and especially in certain seasons, as in 1930, were a decided factor in pollination of an orchard at Blomidon, but, in 1931 were much less numerous. In 1932 there was an apparent increase at some points, but, taking the area as a whole, they cannot be considered an important factor in apple pollination. There is considerable testimony to the effect that the bumble bee population has declined in recent years. Formerly, it is said that they were common in more or less damp meadows where hand mowing had to be resorted to, but are now much less frequently found, especially in the Valley proper. Whether this is actually the case, and whether, if true, it is due to limitation of breeding places, poisoning, or some other factor, cannot now be determined.

The following is a list of the species taken at apple bloom:—

Bremus vagans Smith	*Bremus fervidus* Fab.
" *terricola* Kirby	" *ternarius* Say
" *borealis* Kirby	

4. SOLITARY BEES

By far the greatest number of visitors to apple bloom in the area studied belong to the genera *Halictus* and *Andrena*. The following is a partial list of the species taken:—

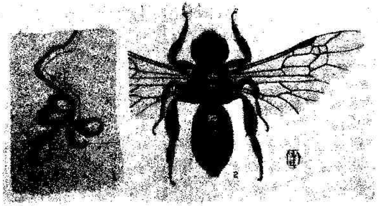
Halictus smilacinæ Robt.	*Andrena carlini* Ckll.
" *craterus* Lov.	" *wilkella* Kirby
" *lerouxii* LeP.	" *cratægi* Robt.
" *arcuatus* Robt.	" *rugosa* Robt.
" *cressoni* Robt.	" *milwaukeensis* Graen.
" *provancheri* D. T.	" *bradleyi* Vier.
" *pilosus* Smith	" *weedi* Vier.
" *planatus* Lov.	" *miranda* Sm.
" *foxii* Robt.	" *vicina* Smith
" *pectoralis* Smith	" *thaspii* Graen.
" *coriaceus* Smith	
" *versans* Lov.	

Of the foregoing the first three species are probably most generally abundant and of these *H. smilacinæ* Robt. far outnumbers all others and is probably more important in apple pollination in the Annapolis valley than all others combined. Next to these in numbers observed on bloom would come *Andrena carlini* Ckll. and *Andrena wilkella* Kirby, the latter common everywhere, but particularly so on Long island.

It has been confidently stated by many writers that modern methods of culture have reduced the nesting places for bees, which fact is said to account for their scarcity. It is of interest to examine this statement in the light of the information gained during this investigation regarding the habits of the species concerned. All are ground-nesting species, living in tunnels which they dig in the earth and provision with pellets of pollen mixed with nectar, on which the eggs are laid and upon which the young feed and develop. In the case of Halicti studied the males occur in the late summer and autumn and only the fertilized female winters over. With the Andrenæ studied, the males occur in the spring. The males, however, are of little significance in pollination.

In the case of *H. smilacinæ* Robt., the most abundant and widespread of all the species taken, the holes may be found scattered in various places. Some are found on exposed surfaces; in other cases the holes are partly covered with vegetation. In favoured situations they may be grouped together in considerable numbers as on roadside banks. They are common along orchard roads if not too much shaded. They seem to prefer for this purpose a sandy loam containing a considerable intermixture of silt and clay.

The nests of *H. craterus* Lov. are found in many different types of situations, but are particularly abundant in sparsely covered pastures, drier part of dyke lands, etc. *H. lerouxii* LeP. nests are also very widespread, but were found in thousands in the "running dyke" at Grand Pré. The nesting habits of *H. arcuatus* Robt. are particularly interesting. It was found nesting only in one location, but here it occurred in countless thousands. This community was found on the steep slope of a pasture on the side of the North Mountain near Centreville. The soil was classified as sandy loam but contained a considerable intermixture of clay. The site was overgrown with wild grasses, asters, golden-rods, thistles and other plants common to such situations. These plants grew largely in clumps, leaving patches of bare ground between and small



1.—*Halictus arcuatus* Robt. Adult and nest (original).

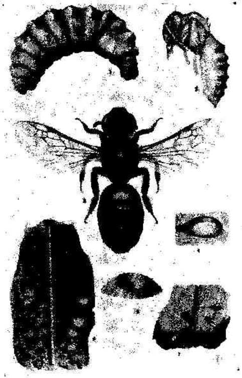
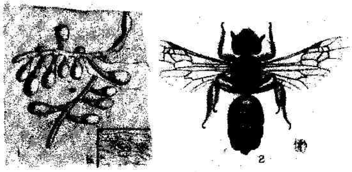


FIG. 32.

2.—*Halictus craterus* Lov. 1, larva; 2, pupa; 3, adult; 4, larva on pollen pellet; 5, entrance to nest; 6 and 7, nest (original).



3.—*Halictus smilacinae* Robt. Adult and nest (original).

boulders up to the size of a football were scattered over and through the ground. A shovelful of earth from this area might contain scores of adult bees, larvae and pellets, and on a hot day when activity was at its height the face of the bank was reminiscent of the front of a bee-hive.

Other species are also associated more or less with a certain type of location. For example, *Andrena wilkella* Kirby though widely abundant, is particularly associated with dyke lands.

FIG. 33.—"Running dyke" at Grand Pré. A favourite nesting place of *Halictus lerouxii* LeP. and other bees (original).

Without pursuing this subject further, it may be pointed out that roadside banks, pastures and dykes do not represent exactly wild conditions, but are the product of human activity. However, neither are such locations intensively cultivated. Cultivated land and certain soil types, such as light sand or gravel, are not suited to nesting, which is one reason that the solitary bees are more numerous in such places as Long island and along the North Mountain, than they are at many points situated in the middle of the Valley.

The results of a more extensive study of the biology and classification of the solitary bees concerned in apple pollination, carried out in connection with this investigation by Mr. C. E. Atwood, will appear elsewhere.

5. FLIES AND OTHER INSECTS

Large numbers of Diptera, particularly Syrphidae, have been taken from apple bloom, in numbers intermediate between those of solitary bees and bumble bees, but neither their structure nor habits lend themselves, to the same extent as bees, for cross-pollination purposes. We are convinced that, outside the two

FIG. 34.—Bank by roadside containing numerous nests of *Halictus smilacinae* Robt. (original).

FIG. 35.—Well trodden foot path. *Halictus foxii* Robt. was nesting here (original).

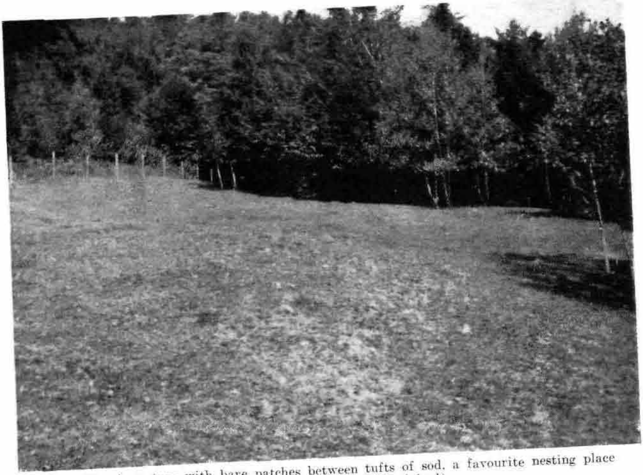


FIG. 36.—A pasture with bare patches between tufts of sod, a favourite nesting place of *Halictus craterus* Lov. (original).

... Robt. (original).

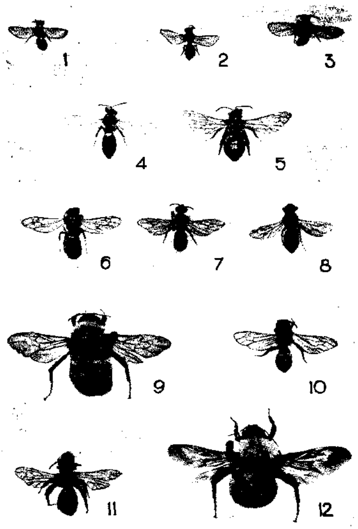


FIG. 38.—Some species of bees involved in pollination of the apple: (1) ***Halictus smilacinae*** Robt.; (2) ***H. provancheri*** D.T.; (3) ***H. arcuatus*** Robt.; (4) ***Andrena crataegi*** Robt.; (5) ***A. carlini*** Ckll.; (6) ***Halictus lerouxii*** LeP; (7) ***H. coriaceous*** Smith, (8) ***Andrena wilkella*** Kirby; (9) ***Bremus ternarius*** Say; (10) ***Andrena milwaukeensis*** Graen.; ((11) ***A. vicina*** Smith; (12) ***Bremus fervidus*** Fab. (original).

genera mentioned, other insects play a minor role, and for this reason they have received little attention in these studies. The following are among the Diptera* taken on apple bloom:—

Bombylius pygmatus Fab.	*Syrphus torvus* O. S.
B. major L.	*Cartosyrphus slossonae* Shann.
Eristalis arbustorum L.	*Sphecomyia vittata* Wied.
E. bastardi Macq.	*Sericomyia militaris* Walk.
E. compactus W.	*Odontomyia interrupta* Oliv.
Rhingia nasica Say	*Hylemya* sp.
Melanostoma pictipes Big.	*Brachyopa perplexa* Curran
Syrphus wiedemanni Johns.	*Pollenia rudis* F.
S. rectus O. S.	*Mericia ampelus* Walk.
S. amalopis O. S.	*Criorhina badia* Walk.

In addition to the foregoing, insects of other families and orders, as noted by other workers quoted, were also observed by us. Since their practical importance as pollinators of the orchard is quite insignificant, they have, however, been given no special attention.

*Determined by Mr. C. H. Curran.

D. RELATIVE VALUE OF INSECT POLLINATORS

1. GENERAL

In view of the situation that exists in the area studied, it was important to determine whether the wild bee population was adequate to ensure pollination under all conditions. This involved the working out of a method of determining the bee population or, at least, the *effective pollinating population;* and it also involved a comparison of the various wild bee pollinators with the hive bee with respect to the various factors affecting their value as pollinators of the apple. In this connection it was not considered necessary to embark upon a study of the very complicated problems dealing with the response of the species concerned to colour, odour, form, etc. Since only a single plant species was involved the problem was considerably simplified, and the limitations of time and expert assistance precluded any particular attention being given to many lines of work, which, while of great scientific interest, were not strictly necessary to the main project. Similar limitations compelled us to lump together all solitary bees under a single heading and treat them as if they represented a single component. While it is recognized that differences exist among the species concerned, with respect to habit and value as apple pollinators, no other course was possible, nor is it likely that it would have affected the practical results of our studies.

2. METHOD OF STUDY

One of the most important practical difficulties was in devising a ready method, applicable to work in the field, for estimating what we have called " effective population," that is, the bee population available for pollinating purposes.

(*a*) ESTIMATION OF EFFECTIVE POPULATION

In order to estimate the relative numbers of different insects present in the bloom, a definite plan was adopted and carried out throughout the entire series of investigations. Workers were stationed at different points in the orchard and made ten minute counts of the numbers visiting the bloom during that period; 250 blossoms representing the unit of observation. The observations were then recorded, together with the records of temperature, humidity, wind velocity, sunlight, etc., prevailing at that time. When studies of distribution were being made, for example, a certain number of counters were placed at suitable intervals throughout the orchard and left there throughout the day, while others " scouted " the outskirts to secure the limits of the flight. (Each counter took up 6 different points during the hour so as to equalize variations from more or less favourably situated limbs.) At Kentville one man was kept at this work throughout the entire blooming period each year, taking observations on different varieties as they became attractive.

In utilizing the figures obtained in these counts as a basis for calculation, we determined the average number of blossoms present per acre of bearing trees in full bloom, by first tagging a representative number of limbs, determining the percentage that set fruit, securing the total crop obtained and, from this, computing the number of blossoms that must have been present to produce this crop. From this it was possible to calculate the approximate number of bees per tree or per acre represented by any count. Thus one bee taken at a single count would represent approximately 4,000 bees per acre present in an orchard with trees all in full bloom at one time.

These figures approach accuracy in so far as the stations chosen represent typical conditions existing throughout the entire orchard. Naturally, it would be difficult to ensure that the stations chosen were absolutely representative, but the comparative results for hive and wild bees are based on identical con-

FIG. 39.—An acre of trees in full bloom, as shown, provides approximately 1,000,000 blossoms (original).

ditions and should be indicative. Furthermore, the consistency of the results obtained, when checked by various methods, indicates that in estimating the effective population the foregoing method is decidedly useful for comparative purposes and the results should be regarded mainly from this standpoint.

(*b*) OBSERVATION STATIONS

Observation "stations" from which our studies of bee activity could be carried out were selected in most cases, with a view to their geographical isolation. Complete isolation could not be obtained, though, in one case, practical isolation was secured. Most of the orchards were chosen from positions near the North Mountain, where "coves" running into the mountain offered partial isolation and at least prevented the bees from flying northward. Nine such sites were selected, but our main observations were carried out at four of these stations, with a fifth in 1932. Brief descriptions of these are given, which with accompanying maps and photographs should give a reasonably clear idea of the situation of the orchard and the character of the territory concerned.

Station No. 1, Experimental Station.—Including a small adjacent orchard, there is available here about 70 acres of orchard practically in a block. It is partially isolated as far as effective bee flight is concerned, from other apple bloom by ravines, belts of trees, etc., on all sides except the north, where the bees can fly across the Cornwallis river, to the large orchards on the other side, distant about a mile. That they actually do this when the bees are placed at the north of the property adjacent to the post road, has been repeatedly observed. Until 1931, colonies were distributed through the orchards, about 50 being available, and these were weakened with poison. Instead of being placed one in a place as in former years, in 1931 and 1932 they were placed in groups in such a way as to secure optimum distribution, and the number was reduced to 37.

Station No. 2, Lakeville.—Here the colonies were placed in a solid ten-acre block of Blenheim, immediately surrounded by orchards, amounting in all to about 90 acres, about half the area being in orchard within an area enclosed by a line drawn at one-quarter mile around the orchard on all sides.

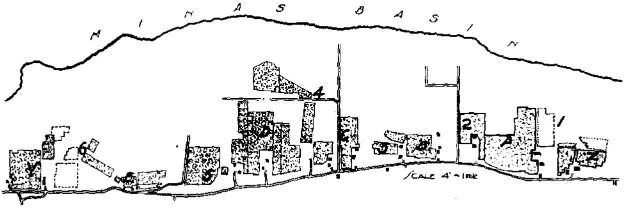


FIG. 40.—Map of Long island district. Total area, 640 acres. Area in orchard, 96 acres. Figures represent stations at which apiaries are situated; letters indicate intermediate points at which counters were placed (original).

Station No. 3, Pereaux.—Within a quarter of a mile radius from the colonies at this station we have 30 acres of orchard in a territory of about 200 acres. The North Mountain at the back of the orchard prevents flight in this direction. This orchard is more or less typical of several others used in these investigations.

FIG. 41.—Aerial view of Lakeville district (by courtesy of Department of National Defence).

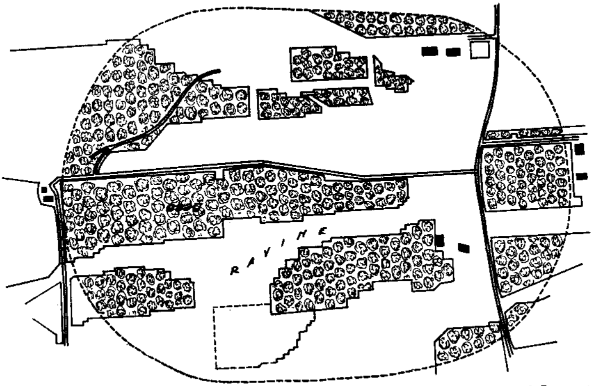


FIG. 42.—Map of Lakeville district. Total area 223·6 acres; area in orchard 93·7 acres; scale 4″=1 mile (original).

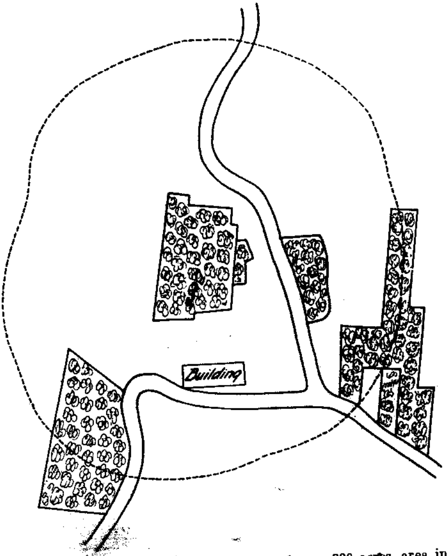


FIG. 43.—Map of Pereaux district. Total area 220 acres, area in orchard 30 acres; scale: 4″=1 mile (original).

Station No. 4, Long Island—This is not now an island being connected with the mainland by two miles of dyke land, which however, affords little bee pasturage until the clover flow. It is two miles long and about ¼ mile wide at the crossroad, bearing about 90 acres of orchard, and with a total area of 640 acres. In 1928, 1929 and 1930 there was available at the east end of the island an apiary of 25 strong colonies situated just north of the east orchard, with a belt of trees between it and the beach. In 1931, colonies were placed on the island at the equivalent of about one per acre divided into three lots, one at each end and one near the centre. In 1932, these were divided into six equal lots placed equidistant from each other. The period of apple bloom is normally several days later than on the mainland and we could never find that, at this particular period, there was any flight off the island.

Station 5, Somerset.—This orchard was selected for certain studies of inter-fruitfulness, using bees as pollinators. They were placed in an orchard of 1¾ acres, with an acreage of 44 within a one-quarter mile radius, and 137·72

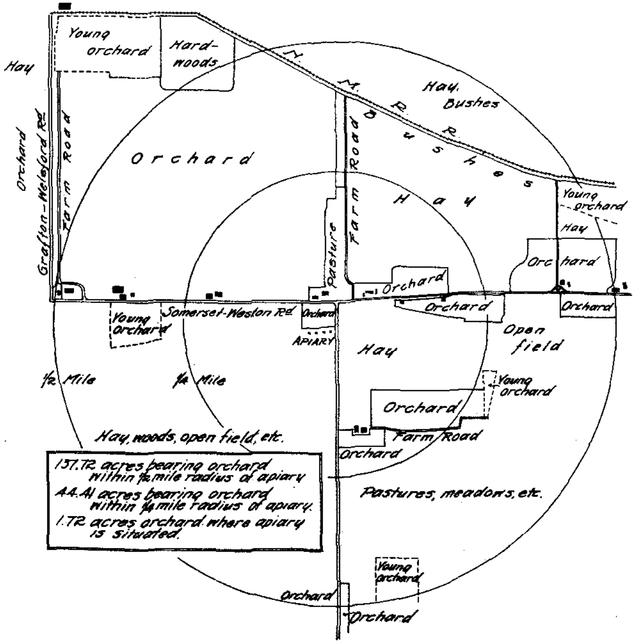


Fig. 44.—Map of Somerset area (original).

acres enclosed in a half mile radius. Fifty colonies in good condition were placed in this orchard and counts were made in and around the orchard for the two days of maximum bloom.

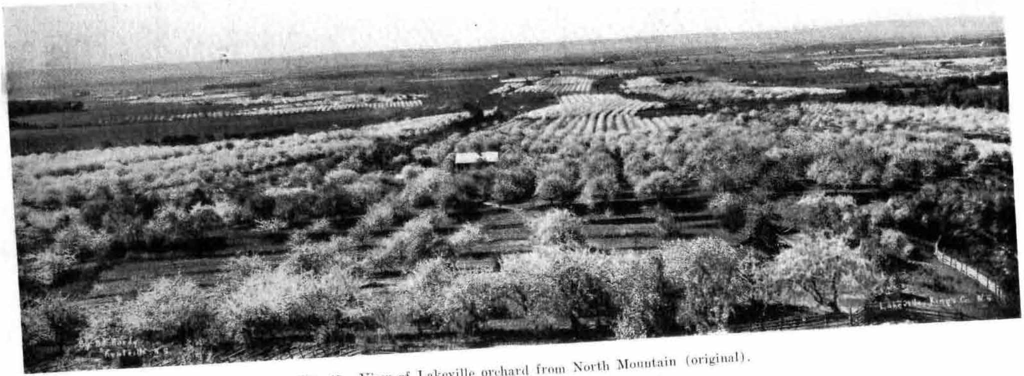


FIG. 45.—View of Lakeville orchard from North Mountain (original).

3. RELATIVE ABUNDANCE OF HIVE BEES AND WILD BEES DURING BLOOM

The following important advantage is claimed for hive bees and may here be discussed in the light of our own observations and those of other workers. *The hive bee is the only species in which the workers winter over, and hence more individuals are available for pollination than in the case of wild bees in which only the queens hibernate.*

The fact that only the hive bees *over winter* their workers is, of course, true; and in view of the fact that only queens among the wild species hibernate, the number of individuals sometimes present in the spring is nothing short of surprising. Various workers, as already noted, have made observations on this point, but only a few have attempted actually quantitative determinations. Therefore the results of our own detailed studies on this point are of interest.

Some useful calculations as to the relative abundance of hive bees and wild bees under known conditions may be based on our work on Long island, Kings county, N.S. At this station we had an excellent opportunity to make comparative studies of the bee population, both of the hive and the wild species. Owing to the isolation of this area and the fact that it came into bloom a little later than the mainland, there was apparently no flight off the island. At the time of apple blossoming there was also available a certain amount of blueberry, rhododendron, dandelion, and other wild flowers, though of course apple predominated.

In 1931 and 1932 when bees were placed on Long island at the rate of one colony per acre, we obtained an average 10-minute count of 1·94 bees in the first year and 3·05 in the second. Since, in 1932, there was only about 60 per cent of the bloom of the previous year, this would indicate little difference in the effective population, assuming that there would occur a greater concentration of bees on the smaller number of blossoms. The solitary bees in the same area were present in greater numbers in 1931, *i.e.*, they were present in the bloom in greater numbers than a field force released by one strong overwintered colony of hive bees per acre. In 1932 the number was less, corresponding to an apparent decrease in the solitary bee fauna from all stations. This observation may be correlated with a heavy mortality occurring among the solitary bees in the summer of 1931, apparently due to drowning in the nests following wet weather. The dry summers of 1928-1931 may have been particularly favourable for the numerical increase of solitary bees. The average number of wild bees taken at all stations for all years would indicate an effective population equal to that released by a concentration of one hive bee colony per acre. If our blossom counts truly represent the facts, they would indicate that about one-third* the field force of the colonies was available for pollination purposes during apple bloom and, if we are to assume that every solitary bee found is potentially a pollinator, then the "effective" population is even greater, for not all hive bees carry pollen. Counts of 7,000 bees made during apple bloom at Ottawa, showed that less than 25 per cent were pollen gatherers and even if we consider double the number are effective pollinators, these figures would appear to indicate that under favourable conditions for pollination, the solitary bee population available during the period under review is sufficient alone to effect the pollination of the fruit crop.

Records of activity from Ottawa, Ontario, and Abbotsford, Quebec, supplied by Mr. C. B. Gooderham, while based on too small counts to permit of generalization, indicate that, while hive bees are present in great abundance owing to the greater prevalence of beekeeping, wild bees, while less numerous, were present in sufficient force to accomplish pollination under normal conditions.

* Measurements made by C. B. Gooderham at Ottawa on 3 colonies showed 61%, 38% and 48% respectively, as the percentage of the total force going into the fields during apple bloom.

The fact should be strongly emphasized that our studies of wild bees have been carried on for too short a time to enable us definitely to state that *they can always be depended upon* to pollinate the orchards in the area studied. It is of interest, however, to note that over a period of four years our counts of hive bees from orchards where they were placed in supposedly adequate numbers to effect pollination, averaged 2·34 per count; and wild bees 1·42 per count, which, even allowing a much greater proportion of effective pollinators for the hive bee than our counts indicate, still leaves a comfortable margin in favour of the solitary bees so far as mere numbers of pollinators are concerned. That each solitary bee will pollinate as many blossoms as a hive bee, however, cannot be definitely stated, but is discussed in another section.

TABLE No. 16.—AVERAGE NUMBER OF HIVE AND WILD BEES PER 10-MINUTE COUNT UNDER CONDITIONS PERMITTING FLIGHT

Locality	1929		1930		1931		1932		Remarks
	Hive	Wild*	Hive	Wild	Hive	Wild	Hive	Wild	
Long island	9·25	2·75	1·47	2·26	1·94	3·01	3·05	1·38	Hive bee counts not comparable in different years, due to varying number of colonies used. In 1931 and 1932 equivalent to one colony per acre. More effective distribution in 1932.
Kentville	1·28	1·40	3·51	1·66	0·77	1·87	1·58	0·14	Counts omitted first four days and last two days of bloom in 1931. Thirty-seven colonies for 70 acres of orchard in 1931 and 1932, all weakened by poison, especially in 1931.
Lakeville			1·15	1·21	1·06	1·87			Forty colonies placed in a 40-acre Blenheim orchard in 1931. Only 16 colonies available in 1930.
Somerset							5·52	1·40	Fifty colonies placed in a 1¾-acre orchard with 137 acres of orchard available within one half-mile.
Blomidon							2·83	0·66	Ten colonies to cover several acres of orchard within one quarter mile. Other bloom scanty.
Scott's bay							5·05	1·36	Ten colonies to cover about one and one-half acres.

*"Wild" bees refers only to solitary bees, not to bumble bees.

4. ARTIFICIAL INCREASE AND DISTRIBUTION

Another advantage claimed for the hive bee as a pollinator is as follows:—

Hive bees only can be artificially increased and evenly distributed in the orchards. This is a decided point for the hive bee as an orchard pollinator. There is no method of artificially increasing the population of wild solitary bees such as Halicti and Andrenae should their numbers become depleted from any cause, and, while investigators have succeeded in "domesticating" bumble bees, no one has ever suggested a method of carrying it out on a commercial scale. On the other hand, bee colonies can be obtained by rental or purchase and furnish a ready method of providing orchard pollinators, where observation indicates a shortage of wild species. Furthermore, they can be so placed as to secure efficient distribution. In addition they can be moved about at will as needed.

5. COMPARATIVE EFFECT OF CLIMATIC FACTORS ON WILD AND HIVE BEES

A number of workers have discussed the general effects of climate, only a few of which can be noted at this point.

In discussing the effects of temperature on bees, Phillips (1927) points out that body temperature is the same as or slightly higher than that of the sur-

rounding air, though in flight it is considered that it is a few degrees higher. During the active season bees may remain away from the hive all night, a fact also noted in our studies.

Studies were made by Hutson (1926) as to the activity of honey bees in orchards at blossoming time and the factors influencing it, especially with reference to the effect of hive placing and weather. The factors directly affecting honey bee flight were said to be (1) temperature, (2) sunlight, (3) moisture and (4) air movement. Temperature was stated not to have been a large factor in honeybee flight in these studies. Little influence was exerted by humidity, short of actual precipitation, which stopped flight. Sunlight was said to favourably affect flight, but did not urge bees into the air if other conditions were unfavourable. Wind proved an important factor in honeybee flight in these studies, little flight taking place when the wind was above 20 miles per hour. This worker and most others have given the major part of their attention to the activity of the hive bee.

According to Phillips (1930) the flight of bees is limited by temperature, wind and moisture. He states that, at 60° short flights are possible, free flight taking place at 65° and full flight at 70° F., while some wild bees, especially bumble bees, fly at a lower temperature. He notes that a wind of 25 miles per hour stops bee flight, lower velocities greatly retard it. Sunshine is not necessary for flight, but cloudy weather keeps the bees near the hive by confining them to short flights. He also states that, even in summer, a sudden shower will reduce the day's flight by 10 per cent or more, while rain or mist stops flight.

DeOng (1925) gives tables to show that rain stops the flight of honey bees, even at temperatures of 52° to 70° F., while on clear days the bees work at all temperatures above 48° F. He believes that these figures probably apply to all bees.

Marshall, Johnson, *et al.* (1929) state that bees are most active on bright warm days, that they do not fly readily at temperatures below 52-56° F., and that a wind velocity of 20 miles or more per hour is unfavourable to their activity. They state that bees prefer to fly against the wind when moving to the field, and with the wind when returning with their load. Though they may travel a considerable distance in good weather, their flight is limited to a few hundred yards during bad weather, according to these workers.

Lundie (1925) in a survey of the total daily exits and returns for the period of the observations, found that a factor or group of factors can reduce the total number of possible exits by an amount varying from total prohibition of flight to a fraction of 1 per cent. A threatening storm, for instance, of but one hour's duration, reduced the possible flight on one day in the honey flow by 7·41 to 9·67 per cent.

Comparatively few data were obtained by this investigator on the effect of wind on the flights. On one day, however, a wind velocity of 16 to 21 miles per hour, during the hours 9 a.m. to 6 p.m., reduced the possible maximum flight by 28·53 per cent.

Under a particular set of conditions, the temperature at which the day's flight commences was found to be uniformly near a certain definite temperature; but this definite temperature is not always the same. In April it was from 12° to 14° C. and in May from 16° to 18° C. On dull days this temperature was usually 2° higher. The internal conditions of the colony govern this temperature somewhat, a strong colony commencing flight at a lower temperature than does a weak one.

There was a considerable variation in the hour and temperature at which the peak of the flight in the honey flow occurs. No conclusive evidence has been obtained that under similar conditions a good honey flow induces the bees to go out in large numbers at a lower temperature than they would if no nectar

were available. The temperature at which the flights in the evening began to slacken was, without exception, from 1° to 9° C. higher than the temperature at which flight began in the morning. Days which appear to be similar in every respect, but which show a variation of as much as from 10 to 25 per cent in their total flights, are found to differ on account of a lower temperature in the early part of the day.

Observations by Woodrow (1932) during apple bloom, indicate that the temperature of greatest activity may differ in different types of colonies. Flight began at lower temperatures and was proportionally much heavier in the lower temperature ranges from the stronger colonies; but, at the higher temperature ranges, there was a proportionally heavier flight from the weaker colonies. The point of greatest activity was reached at 76-78 degrees F. for a colony containing 1·63 pounds of adult bees; at 82-84 degrees F. for an 8·25-pound colony but there was little significant difference in this colony from 76-78 degrees upward. Indeed, from 62-64 degrees upward there is considerable overlapping in the number of workers leaving the hive. For example, the average flight at this range was 206·25 bees per minute, compared with 202·67 at 78-80 degrees F. This would seem to indicate that the maximum flights should occur in strong colonies from 60° F. upward, but in weak colonies such flights would not be expected until over 72° F.

MacDaniels (1930) considers wind velocity the greatest limiting factor of pollination in western New York. Park (1923) notes that bees make little progress against a wind of more than 15 miles per hour.

The period of apple bloom occurs at a time of uncertain weather. Low temperature, rains, cloudy weather, and such conditions are sometimes responsible for low crop yields, through inhibiting the flight of insect pollinators, as well as creating generally conditions unsuitable for pollination. The following data collected during apple bloom, represent observations over such a short period that they should be studied in connection with the supplementary data obtained during the golden-rod flow later in the season.

(*a*) TEMPERATURE

With respect to temperature, the following claim has been made on behalf of the hive bee:

Hive bees work at lower temperatures than do wild solitary bees. It should be understood that our data relate entirely to bee activity in *apple bloom.* Frequently, bees were noticed working on dandelions and other low growing plants when none could be detected in the trees.

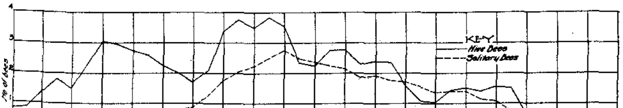


FIG. 47.—Relation of hive bee activity in apple bloom to temperature, 1929-1932 (original).

So far as this factor influences activity in apple bloom, the optimum for both the hive and the wild species, confining the latter term to *Halictus* and *Andrena* and not including bumble bees, on the basis of our observations, appears to be nearly the same, viz., about 68° F. for wild bees and about 67° F. for hive bees. It should be noted that in our counts a greater number of observations were made at the lower ranges of temperature. Hence our averages for

these ranges are based on a larger number of counts and this no doubt affected the point of apparent optimum activity. Had higher temperatures throughout the bloom been the rule rather than the exception, the point of apparent optimum activity might have been higher. The results of other workers already noted, and of supplementary observations made on this point, and presented later in this report, indicate that this is the case. At the same time it should be borne in mind that the temperature of greatest activity may be lower early in the season, as noted by Lundie (1925). Observations made throughout the entire day indicate that the hive bees begin to work earlier in the morning and usually persist later in the day.

Above the temperature indicated they worked well up to 80° F., but the number found at work over 90° F. was insignificant. It should be said, however, that such high temperatures very seldom occur during apple bloom. Small numbers were found at work at temperatures as low as 50° F., *i.e.*, actual orchard temperature, and rarely at lower temperatures; and, with all other conditions favourable, fair activity was observed at temperatures as low as 57° F. A temperature of 65° F. is usually given as the minimum effective temperature, but we would be inclined to place this figure somewhat lower, provided other factors were favourable. With reference to the effect of temperature on the distance of flight from the colonies, the statement of other workers that only short flights are made during the lower temperature ranges, as is also the case with other unfavourable factors, would appear to be well substantiated. At 65° F., however, there appears to be no evidence of flight limitation, and at 70° F. maximum flights are to be expected.

Hive bees do not appear to be as sensitive to slight changes in temperature as do many of the wild species, and a larger proportion is found at the lower temperatures. They also seem to be more erratic in their response to temperature during their work in the bloom than do the wild species. This is brought out in the accompanying figure which shows the curve for wild bee activity more consistent than that for hive bees. This is not believed to be due entirely to errors in methods of sampling, since the same method was used for both wild and hive bees. It may be that hive bees are more sensitive to other influences which modify temperature effects. They appear, for example, to show a greater tendency to concentrate in locations where bloom is in a particularly favourable condition. Another factor that appears to make the temperature response somewhat erratic is the fact that the sudden breaking away of clouds, clearing up of a fog or similar condition, causes the hive bees to come out with a rush, thus giving what appear to be abnormally high counts for those periods. The modifying effect of light conditions is discussed in the next section. It is clear from these observations that our counts fall off rapidly as the lower light readings are recorded in the late afternoon, even though temperature conditions remain constant or recede at a much less rapid rate. In fact, in some cases we have reductions in numbers of bees even with a temperature rising to an apparently more favourable point. Our records show an apparent difference in temperature response between morning and afternoon, higher values being indicated in the morning readings, which indicate that the effect of each degree of temperature, within a given range, is of varying value, depending on light conditions. Temperature—conditioned by light and modified also by wind, nectar secretion, pollen availability, colony strength and similar conditions—is a crucial factor in bee activity during apple bloom.

It should be emphasized, therefore, that the response to temperature cannot be considered apart from light, wind and other factors. Hence, we can only state in a general way what the optimum temperature range for bee activity is. The temperature at which the highest average number of bees is taken, might be very different in different localities, different seasons, different times of the same season, different days, or even different periods of the day, owing to the modifying

influence of light, wind and other effects. The peak of the activity curve, therefore, represents the largest average number taken at that particular temperature during apple bloom over a four-year period, but it does not necessarily represent the true optimum temperature for general bee activity. Also, the apparent falling off in activity after the peak may be attributed to the comparatively small number of observations made at the higher temperatures. During golden-rod flow, which occurred at a time when higher temperatures were the rule, there was a steady increase in activity up to 84° F., which was the highest observed temperature.

Lundie's (1925) statement that the temperature at which flight begins to slacken in the afternoon is from 1° to 9° C. higher than that at which flight begins in the morning, seems, in general, to be substantiated by our figures and is true for both hive and wild bees. This would appear to be a light effect, as brought out in another section.

(*b*) SUNLIGHT AND SOLAR RADIATION

Sunlight is an important factor in influencing the activity of bees, but sunlight alone will not cause them to work provided the temperature is too low. An interesting effect of lack of sunlight is noticed on shaded limbs, the blossoms on which fail to be pollinated to a much greater extent than on limbs exposed to sunlight. Bees respond to sunlight very rapidly, as can readily be observed in weather that is partly cloudy. It was noted that counts made, even at optimum temperatures, showed fewer bees present in hazy weather, even without definite cloud banks, than when the sky was clear. The rapidity with which bees return to the bloom following bursts of sunlight is noteworthy.

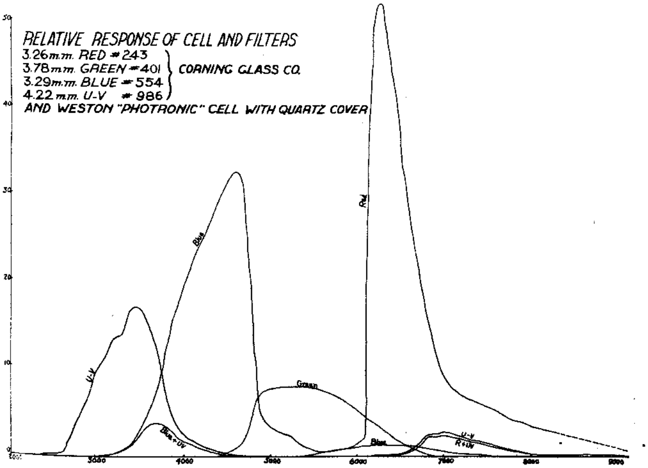


FIG. 48.—Relative response of cell and filters of solar radiation apparatus (original).

The stimulative effect of ultra-violet light on insects has been demonstrated by a number of workers who have investigated the "colour sense" in this class, and several of these have used the hive bee in their experiments. This work has mainly concerned the attraction of different coloured flowers for the insects. It was thought that something might be learned from studying the distribution of solar radiation throughout the day in relation to the activity of hive bees and solitary bees in the bloom, as might be expected from the results of Bertholf (1931 and 1931a) and others.

Through the kindness of Mr. J. Patterson, Director of the Meteorological Service of Canada, who provided us with the necessary equipment for this work and assisted us by means of advice, we were enabled to give this problem some attention during the period of apple bloom in 1932.

The accompanying figure illustrates the relative response of the cell and filters, and the following table shows the percentage radiation falling within the indicated bands, which is effective in producing the galvanometer deflection, the shunt for which was adjusted to about ½ of 1 per cent, the filters calibrated to within 2 per cent:

Filter	Band	Band, per cent	Maximum	per cent at
U-V	2800–3900	11·0	17	3460
U-V	6600–7800	1·8	3	7000
R + U-V	6600–7800	1·6	2	7000
B + U-V	3400–4200	2·5	4	3700
Blue	3550–4950	19·0	32	4600
Green	4750–6150	7·0	8	5100–5400
Red	6080–7800	19·0	52	6250

As the ultra-violet filter had also a transmission band in the red and infra-red, it was considered desirable to take a reading with both the red and ultra-violet filters on the instrument, as well as with each of the filters singly. The ultra-violet radiation was then given by the following formula:

Ultra-violet=U-V—1·14 (R+U-V).

This constant has been evaluated on the assumption that there is a uniform distribution of radiation between 6600 and 7800Å. As the distribution on any occasion is unknown, this assumption was necessary, but the resulting error would be small. The combination of blue and ultra-violet filters was also used, as this isolates a rather narrow band in the vicinity of 3750Å.

Half hourly readings were taken on a number of typical days throughout the bloom and curves drawn to show the distribution of solar radiation throughout those particular days, together with temperature. Curves have also been plotted for bee activity, based on average counts over the same period. In order to allow all values to be placed on a single graph, arbitrary factors have been assigned to each, as indicated.

Furthermore, in order to facilitate inspection of graphs indicating bee activity, the ultra-violet and clear values are indicated on a single chart together with temperature, while the other values are placed on another chart. Since all the observations could not be taken simultaneously, it was not possible to secure exact synchronization of the different readings, and certain irregularities, therefore, resulted.

It will be seen, however, that there is a general trend upward of bee activity, corresponding with increasing light values, and a corresponding decrease when light readings normally fall off in the afternoon; or, from the effects of clouds, haze or fog, at any time during the day. It will be observed, also, that *within the temperature range of bee activity*, light apparently has a more important influence than slight changes in temperature. It will be observed that the bee counts fall off much more rapidly than temperature in many cases. In others

they fall off with receding light values at a nearly stationary temperature and, in still others, there is actually a falling off in activity as light values recede, even with a slightly rising temperature.

We were unable by this method, however, to secure any clear indication that any particular wave length had any greater stimulative effect than any other. In this connection it has been determined by Bertholf (*loc. cit.*) that the

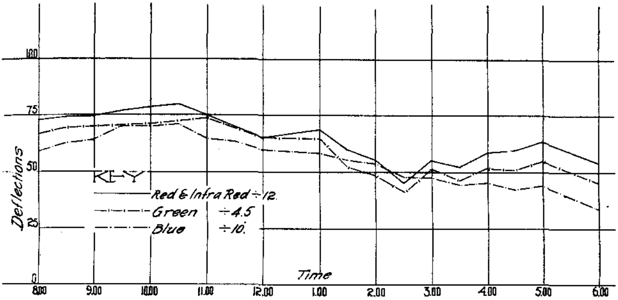


FIG. 49.—Distribution of solar radiation, June 3, 1932 (original).

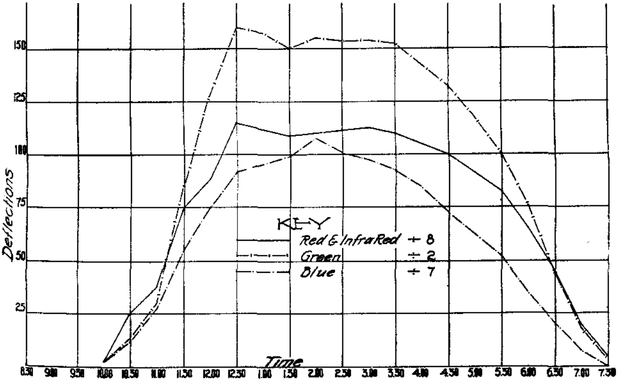


FIG. 50.—Distribution of solar radiation, June 4, 1932 (original).

maximum stimulative efficiency for the honey bee in the non-visible or ultra-violet portion of the spectrum is at 3650Å, and the values for stimulative efficiency fall away rapidly on receding from these values. The greater part of the response of our ultra-violet filter No. 986 lies in the region of 3450Å. The same applies to the green filter No. 401, where the maximum response is in the

region of 5300A, while the maximum stimulative efficiency of light in the visible spectrum (though this has only about 2/9 the stimulative effect of the ultra-violet) is at 5530A. Even though it were possible to isolate narrower bands in the region of maximum stimulative efficiency by means of this apparatus, it is not certain that we would secure any further information in regard to this particular point, because of the tendency for all readings to follow the same general trend throughout the day. Without an automatic recording device for light values and bee numbers, the difficulty of properly synchronizing the two sets of observations is difficult to overcome.

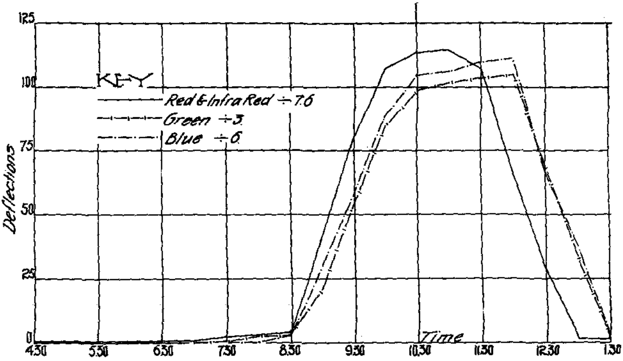
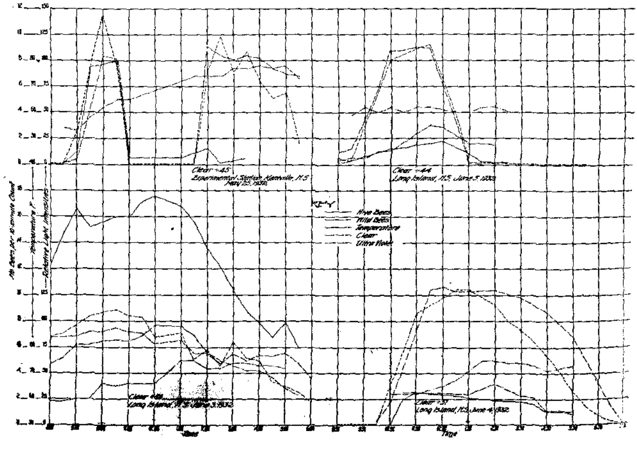


FIG. 51.—Distribution of solar radiation, June 5, 1932 (original).



With respect to the differential response of hive bees and solitary bees it is again difficult to make comparisons, especially as there are unequal numbers of each available. There is a definite indication, however, based on numerous individual observations, that hive bees actually do work more readily at lower light values than do the solitary bees taken as a group.

(c) WIND

Wind is an important factor in governing the activity of bees, as indicated by the observations of other workers already quoted. Winds likewise limit the length of flight of bees in the same way as unfavourable temperature conditions, so that they will be found nearer the hives in sheltered areas during such periods. In our counts, the maximum wind velocity recorded up to and including 1931 was only 13 miles per hour, and even at this velocity there was considerable activity. The observation was made, however, that on the eastern end of Long Island, where belts of wood at the north of the colonies sheltered them from the open basin, the bees worked in greatest numbers.

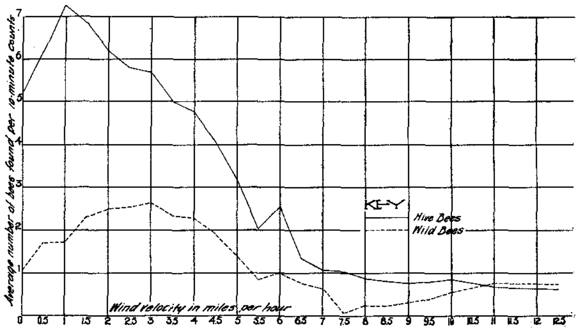


FIG. 53.—Bee activity in relation to wind velocity (original).

It would appear, however, that in the average year during the period of apple bloom and in the situations where the observations were made, wind was not as important an inhibiting factor as reported from certain other areas. In 1932, however, apparent cases of flight inhibition due to wind were observed. A tabulation of the numbers taken at the different wind velocities was made, which, allowing for the usual large number of apparent irregularities resulting from errors in sampling, and from the widely different number of observations at different velocities, seems to indicate a decided influence for even very low velocities. This can best be observed by reference to the preceding graph which has been smoothed by the method of moving averages.

There is no indication of interference with flight in the case of hive bees up to 1 m.p.h. and for wild bees up to 3 m.p.h., after which the counts began to fall off. From the foregoing it would seem that, in locations where high winds are frequent, this factor may be of the utmost importance in pollination, but our own records are inadequate to allow of any more definite statement.

Our records would also seem to show that wild bees during the same period appeared to be somewhat less profoundly affected by changes in wind velocity than are the hive bees. The number of observations taken, however, are insufficient to enable us to state with certainty that this is the case.

(*d*) HUMIDITY

Humidity, short of actual rainfall which checks flight, is generally regarded as having little influence on bee activity. Bees have been noted gathering moisture from a nearby spruce hedge during a light rain and, in one case, bees in front of a large apiary composed of particularly strong colonies were noted working on rhododendron bloom during a drizzling rain at a temperature of 60° F., but no bees were noted on trees or from weak colonies under such conditions. Water collectors appear to come out on their short flight even during a light rain and during intervals between rains, when other bees remain in the hive, and this has been observed to be a factor in poisoning, such bees gathering poisoned water from leaves on sprayed trees or from herbage growing in sprayed orchards.

The numbers of bees taken at the different relative humidities experienced during the course of these investigations have been tabulated and studied without our being able to detect any direct effect of relative humidity on activity of either hive or wild bees, up to the point of actual precipitation.

(*e*) INFLUENCE OF TIME OF DAY

The curve of activity throughout the day is of interest because it represents the combined effects of temperature, light, and possibly other factors such as

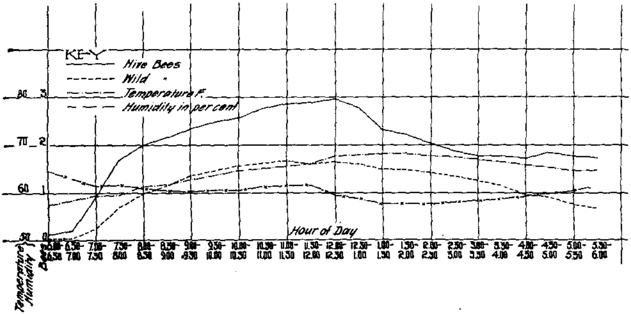


FIG. 54.—Average bee activity at different diurnal periods in connection with humidity and temperature, 1929-32 (original).

the possible exhaustion of nectar and pollen supplies. As indicated in the foregoing chart (smoothed by the method of moving averages), it will be seen that this follows a fairly regular curve reaching a maximum for hive bees at 12-12.30 p.m. and for solitary bees at 11-11.30 a.m. Temperature and humidity have been shown for comparison.

TABLE NO. 17.—TABLE SHOWING AVERAGE BEE ACTIVITY AT DIFFERENT DIURNAL PERIODS IN CONNECTION WITH TEMPERATURE AND HUMIDITY*

Time	Hive bees		Wild bees		Temperature		Humidity	
	Average number	Number of observations	Average number	Number of observations	Average	Number of observations	Average	Number of observations
6.00–6.30	0	16	0	16	54·5	4	65·5	2
6.30–7.00	0·4	15	0	15	61·75	4	69·0	3
7.00–7.30	0·23	22	0·05	22	60·2	9	62·0	7
7.30–8.00	0·55	*11*	*0·09*	*11*	*61·0*	*1*	*55·0*	2
8.00–8.30	1·29	102	0·40	102	59·24	37	61·24	34
8.30–9.00	2·34	163	1·06	163	59·81	31	62·08	26
9.00–9.30	2·27	227	1·37	227	63·96	52	59·0	45
9.30–10.00	2·35	218	1·50	218	62·73	45	60·3	40
10.00–10.30	2·70	252	1·84	252	65·44	59	59·96	50
10.30–11.00	*2·69*	*220*	*1·47*	*220*	*64·28*	*46*	*62·08*	*40*
11.00–11.30	2·47	244	1·61	244	66·31	58	60·76	49
11.30–12.00	3·46	161	1·58	161	66·27	33	63·81	32
12.00–12.30	*3·00*	*10*	*4·60*	*10*	*63·38*	*8*	*61·14*	*7*
12.30–1.00	1·43	23	1·91	23	72·3	10	51·5	4
1.00–1.30	3·01	213	1·61	213	68·56	57	54·98	46
1.30–2.00	2·27	255	1·47	255	67·74	54	59·67	45
2.00–2.30	1·84	279	1·30	279	68·13	76	58·30	66
2.30–3.00	1·95	237	1·56	237	67·20	56	58·16	51
3.00–3.30	1·42	293	1·20	293	67·38	77	57·58	67
3.30–4.00	1·95	212	1·13	212	66·83	53	58·65	49
4.00–4.30	1·94	223	0·93	223	65·02	64	58·72	61
4.30–5.00	1·89	151	0·74	151	63·63	41	62·12	42
5.00–5.30	1·65	96	0·60	96	65·79	24	60·84	25
5.30–6.00	1·67	6	0	6	60·67	3	67·0	3
6.00–6.30	0	2	0	2	73·0	1	42·0	1

*Actual figures.

Supplementary data on the influence of the various climatic factors are presented in the following pages by Mr. J. M. Cameron, following which a summary of the general effect of these factors is given.

(*f*) SUPPLEMENTARY DATA ON CLIMATIC FACTORS

(J. M. Cameron)

(i) *General.*—Desiring to obtain further information with regard to the effect of climatic factors on bees at periods other than apple bloom, further data were secured in August and September during the period of maximum golden-rod bloom, many other flowers such as fall dandelion, Canada thistle, fireweed, buckwheat, white clover, etc., being also available. Instead of attempting to count visitors to the flowers, however, as was done during apple bloom (1) the bees were trapped for short periods after the manner described by Farrar (1931); (2) counts were made using a photoelectric apparatus; (3) a tripping device was used to register and record automatically the insects leaving the hive. By following the latter two methods we did not, of course, secure counts from the entire hive, but only for a small area in the centre of the brood chamber. It would have been preferable to have secured counts for the entire colony, but, as the necessary apparatus was not available, it was considered that the figures obtained in this way would indicate the comparative activity throughout the day, as influenced by various climatic factors. After experimenting with the other methods, the photoelectric device was retained as giving the most satisfactory and accurate results.

Mr. J. S. Leefe assisted in taking all the records and in compiling the data obtained.

(ii) *Apparatus and Its Manipulation.*—Figures 1, 2 and 3 show the essential details of the counting device. Figure 1 is a diagram of the wiring system

used. There are four different circuits in the hook-up. The primary circuit is that of the photron cell. This is connected with a Weston Model 30 relay (fig. 1, C). As the bee passes through the tunnel (fig. 2, K) it interrupts the light beam passing through the slits Q and R and falls on the cell B. This interruption varies the potential in the circuit and operates relay C. Operation of this relay causes completion of the secondary circuit, a 4½-volt direct current supplied by three dry cells (fig. 1, H). This current in turn operates a second relay (fig. 1, D), which acts as a switch in the 110-volt alternating current line, and operates the counter (fig. 1, E). The fourth circuit has an eight-volt, alternating current obtained through a transformer from the 110-volt line. This supplies the power to a 32 candle-power bulb, such as is used in the ordinary automobile headlight.

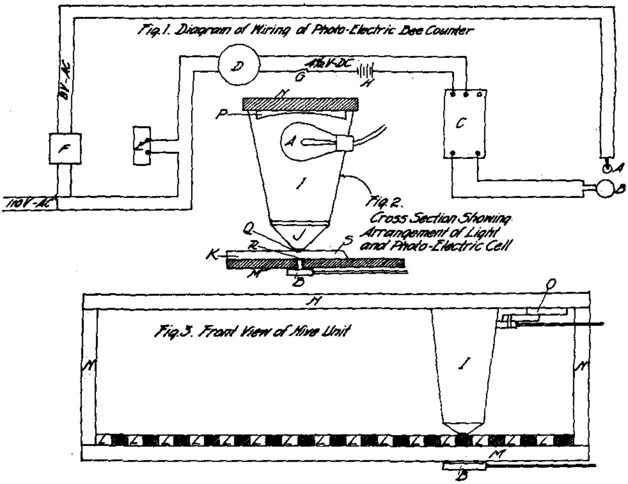


FIG. 55.—Diagram of photo-electric bee counter. (A) 8-volt, 32-candle power bulb; (B) Weston photron cell; (C) Weston model 30 relay; (D) secondary relay; (E) electrical counter; (F) transformer; (G) knife switch; (H) battery of three dry cells; (I) cone-shaped lamp box; (J) Abbé condenser; (K) tunnel (exit); (L) tunnel (entrance); (M) landing board; (N) bracket supporting light; (O) adjustable bracket for light socket; (P) concave mirror; (Q) slit in roof of tunnel; (R) cover slip over hole in floor of tunnel; (S) celluloid trap door at mouth of tunnel (original).

Figures 2 and 3 show the essential details of the hive unit. Figure 3 is a front view, and figure 2, a cross-section. The landing board is cut off flush with the inner face of the front of the hive, and the unit substituted. The entrance is divided into a number of tunnels about three-eighths of an inch square, and approximately three inches long. These are closed at alternate ends by a trap-door, so that passage is possible in only one direction. The material used for the trap was ordinary photographic film hung on two narrow hinges of cellophane. These hinges had to be renewed quite frequently, as the bees often

a slit through one of the exit tunnels, and the centre of the photoelectric cell was placed immediately beneath. This arrangement did not provide a sufficiently strong light to actuate the cell, so an Abbé condenser from a compound microscope was inserted in the beam to concentrate it. This made a great improvement, and the addition of a concave mirror above the bulb gave a sufficiently strong light on the cell to cause very rapid reactions. The instrument as built was quite crude, and by adding refinements, such as the use of a point-light bulb, could be greatly improved.

To operate the instrument, the hive unit was placed on the front of the hive, making it necessary for the bees to enter and leave through the tunnels. The counter was then plugged into the 110-volt current, causing the light to come on, and the knife-switch (fig. 1, G) was closed. This prepared all the circuits, and each time a bee passed out through the tunnel, interrupting the light beam, it was recorded by the counter. Records were taken every quarter hour, and the counter set back to zero.

Light intensity records were taken by means of a photoelectric solar radiation instrument already described. Wind velocities were obtained by the use of a cup type anemometer, and temperatures and humidities by thermographs and hygrographs respectively.

(iii) *Temperature.*—Exits were recorded at the lowest temperature obtained, viz., 52° F. While fairly high counts were obtained between this and 60° F., it is believed that these represent mainly "play flights," as the bees, in many cases, did not leave the immediate vicinity of the hive. Little increase in flight activity was observed until a temperature of 62° F. was reached. From this point until the highest recorded temperature, viz., 84° F., was reached, flight activity showed a steady and almost uniform increase.

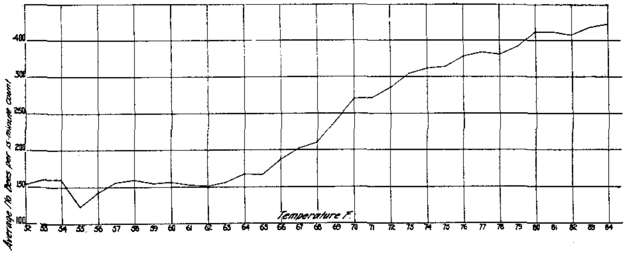


FIG. 56.—Bee activity in relation to temperature during golden-rod honey flow (original).

That the effect of temperature is modified by other factors is clearly brought out by the fact that activity is higher at practically all recorded temperatures in the morning than in the afternoon. Few "work flights" occurred in the afternoon below 68° F., and from this temperature to 58° F. activity remained practically constant and consisted mainly of "play flights." From 58° F. to 56° F. recorded flights dropped rapidly to zero (fig. 60).

(iv) *Light.*—Within the range of conditions permitting free flight, light is the most important factor influencing activity. It is very noticeable that if, on a bright day, a cloud suddenly obscures the sun, outgoing flight immediately drops, while the bees which are out return in large numbers almost at once. This observation was made on several occasions, but unfortunately we had no means of measuring such inward flight.

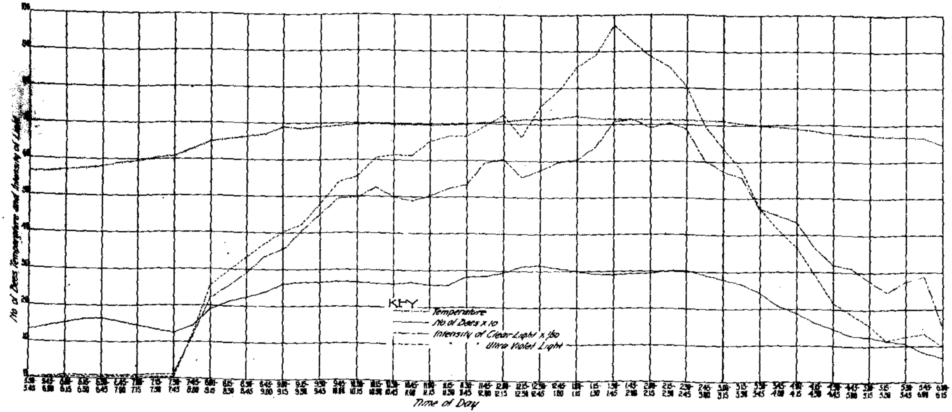


FIG. 57.—Bee activity in relation to light and temperature conditions throughout the day during golden-rod bloom (original).

Flight after about 2.30 p.m. drops off with increasing rapidity. Our counts obtained after about 4 to 5 p.m. cannot be taken as indicative of the actual activity of the colony, as observation seemed to indicate that the flights taking place at this time were largely what are known as "play flights." For the same reason early morning flights, up until about eight o'clock, cannot be taken as indicating working activity. From this standpoint the method of counting bees visiting blossoms, as was done during apple bloom, is a more accurate criterion of field activity than counting the bees as they leave the hive.

The curve of average flight throughout the day, as shown in the chart, follows more closely the changes in light values, and particularly the ultra-violet, than those in temperature. This fact was borne out by calculating simple correlations of the average temperature, intensity of clear light and intensity of ultra-violet light, with number of bees, at different periods throughout the day. The correlations were found to be: for temperature, 0·6686± 0·0520; for intensity of clear light, 0·8429±0·0305; and for intensity of ultra-violet light, 0·9156± 0·0141. From these results it would appear that ultra-violet light intensity is the most important factor influençing the trend of flight throughout the day. That all three conditions acting together probably decide the content of activity is shown by the multiple correlation of 0·9332 which was found to exist.

The importance of ultra-violet light is further shown by the *beta*-values calculated. These were, for ultra-violet light, clear light and temperature, 1·2972, —·1709 and —·2584, respectively. Of these, only the value for ultra-violet is significant. The other values are negative and unimportant. This indicates that the high, positive, simple correlation obtained for these two factors was due to their being so closely associated with ultra-violet.

There is considerable variation in individual observations, and these do not show as close correlation as is found in the averages. Individual counts seem to be somewhat more dependent on temperature than on light, the simple correlations of temperature, clear light and ultra-violet light with activity being 0·6179 ± ·0203, 0·5003 ± ·0245, and 0·5346 ± ·0263, respectively. The multiple correlation of these factors, using the 415 observations made, was found to be 0·6517. The *beta*-values in this case show temperature to be the most important factor. Ultra-violet light is also a highly significant factor, while clear light has a significant bearing on activity, but is not as important as are the other factors mentioned.

Taken at their face value, the above results indicate that the average trend of flight throughout the day is more dependent on the intensity of ultra-violet light than on the other factors studied; while any individual count of flight is influenced to a greater degree by temperature. This last condition is probably due to the circumstance that there is a threshold temperature, below which flight will not take place no matter how favorable the light conditions, while above this temperature, even with the light intensities registering practically nil, there is nearly always some flight. The relative unimportance of the clear light factor is hard to understand.

In order to determine further the importance of light in influencing bee activity, records were taken during the partial (93%) solar eclipse of August 31, 1932. Conditions for observation at this time were practically perfect. After the first few observations there was a dead calm. With the exception of one period of about ten minutes no clouds interfered with the ligbt conditions and the maximum drop in temperature was seven degrees F. A glance at the accompanying graph will show the close relation between the light intensities and the bee activity. While the lowest bee count was obtained at the period of lowest temperature, the fact that temperature was not of prime importance is shown when it is remembered that the counts obtained, viz., eight bees, was only a mere fraction of the average count obtained at this temperature.

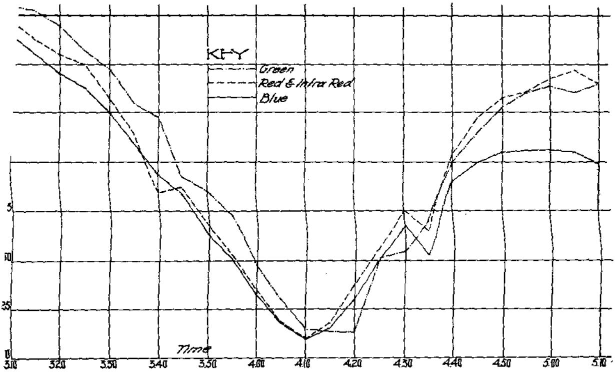


FIG. 58.—Distribution of green, red and blue during partial solar eclipse, August 31, 1932 (*original*).

The rise in activity as the sun again came into view was not as regular as he decrease, partly due to the fact that it was quite late in the afternoon, when light normally falls off fairly rapidly and tends to become more irregular.

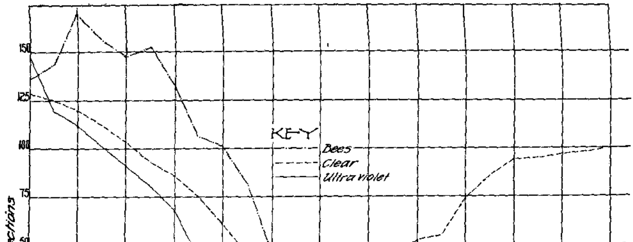


FIG. 59.—Solar radiation in relation to bee activity during partial solar eclipse, August 31, 1932 (original).

(v) *Wind.*—No wind velocities exceeding 4·4 miles per hour were obtaine and owing to varying light and temperature conditions it is impossible to draw definite conclusions as to the effect of this factor on activity.

(vi) *Humidity.*—A study of the data revealed little direct connection betwee bee activity, as measured in flights from the hive, and varying degrees of relativ humidity. While it has generally been stated that actual precipitation con

pletely stops all flight, on numerous occasions flight was noted during light rains. This activity represented mainly " play flights " and flights of water carriers.

(vii) *Activity Throughout the Day.*—The combined effects of the different factors already discussed are indicated in the trend of flight activity throughout the day, as will be seen by a glance at fig. 57. The figures for periods earlier than 8.30 a.m. have only limited value, since they represent the records of two days only.

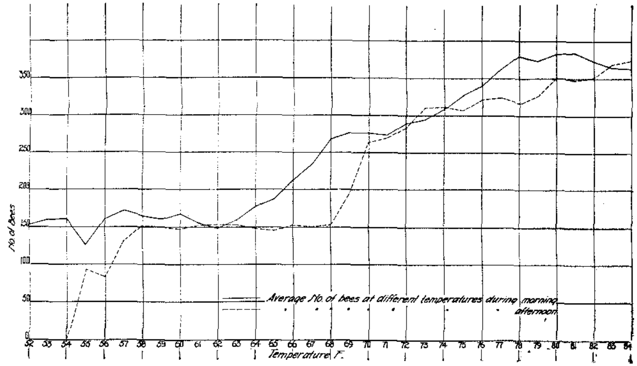


FIG. 60.—Comparison of flight of bees in morning and afternoon (original).

6. NUMBER OF VISITS OF HIVE AND WILD BEES

There is a considerable amount of scattered observation available as to the number of trips made by bees and the number of individual visits to blossoms made in a given time. Most of these observations relate to hive bees. It seems very difficult, however, to arrive at any average figure on the basis of these data or on those secured during the course of our own observations.

Lundie (1925) has observed that the morning and evening flights are very much shorter than those that take place in the main period of the day's flight, a variation of from 15 minutes to as much as 1 hour and 43 minutes occurring in one day. Taking all the days for which the average duration of the trips was determined, it is found that this duration varies from 8 minutes to as much as 1 hour and 54 minutes. In the honey flow the trips are much shorter than they are in a dearth. On the day on which maximum flight occurred it was found that 20·74 trips per bee was the largest possible number that could be made provided each bee entered and left the hive immediately; while the figures available seemed to show that even in a heavy honey flow the bees spent more time in the hive between trips than they did on the trip itself.

Parks (1928) found that one hour was ample time for a nectar carrier, and, under favourable conditions, ten trips a day was considered a fair average. Round trips for pollen may be made in 15 minutes or less, but no conclusion is reached as to the number of trips per day. Water carriers can make a round trip in 5 minutes and may make 100 trips per day.

Dyce (1927) states that the average number of blossoms visited by a colony of bees in a single day is around 21,600,000 or the total number of blossoms on

20 acres if all are in bloom at once. A low estimate of the average number of blossoms visited by a single bee in a day is about 720. McCulloch (1914) records observations in which one bee was observed visiting 61 blossoms, another 53 and several 25 to 40, and many similar observations have been made by us.

If a pollen carrier made only ten trips a day, which, on the basis of Park's figures would mean 2½ hours in the field, it would only have to visit 72 blossoms on each trip in order to attain the figure mentioned by Dyce (*loc. cit.*). The figures given, however, would seem to indicate a field force of 30,000 bees which is considerably stronger than the average colonies obtained by us at this time of year. Moreover, allowance would again have to be made for the proportion of bees not carrying pollen.

On the other hand, not all, and probably not more than half the blossoms on mixed plantings are available in the proper condition for the bees at any one time. If we reduce the field force indicated above by one half and consider that only 25 per cent carry pollen, this would give us an effective force of 3,750 per colony. If each of these pollinated a total of 720 blossoms throughout the entire bloom, it would mean the pollination of 2,700,000 blossoms or the total blossoms on 2·7 acres. Provided that an adequate supply of effective pollen is available, and even allowing for the maximum number of duplicate visits, it would seem, on the most conservative estimate, that the force liberated by a single colony of bees, should be capable of visiting a sufficient proportion of the bloom to pollinate effectively several acres of orchard, the exact amount depending upon the duration of favourable flight conditions. It should be noted that only a small proportion of the bloom needs to be pollinated, which gives a wide margin for failures to be visited, for ineffective pollinations and for duplicate visits.

When we come to the question of bumble bees, still less information is available; though a number of workers have noted that these work more rapidly and cover more blossoms in a given time than do hive bees, a fact which our own observations substantiate. Owing to the small size and rapid movements of our chief pollinator, *Halictus smilacinæ* Robt., however, it was not possible to secure any data of sufficient accuracy to be worthy of record. Hive bees and bumble bees will sometimes be observed following a limb and covering a large percentage of the blossoms before passing on to another, whereas the solitary bees seem to be less consistent in their movements. Though we have no reliable data as to the mixtures of blossoms individual solitary bees may visit in a given period, the observations made in another section, with respect to the actual number present in the bloom, gives useful information as to the relative value of hive and solitary bees.

7. POLLEN GATHERING HABITS

Certain pollen gathering habits may affect the evaluation of hive and wild bees as orchard pollinators. The division of labour among worker bees into pollen carriers, nectar carriers, etc., means that the force available for pollination is reduced in proportion to the numbers devoted to their special tasks. Nectar carriers may carry little pollen and certainly have less value for this purpose than pollen gatherers. They have been observed on many visits to insert their mouth parts into the nectaries from the side, without covering the blossom in such a way as to insure pollination. The relative number of bees which collect pollen and those which collect nectar is, therefore, of considerable importance in connection with this study. Some plants are visited entirely for pollen, some for nectar and some for both pollen and nectar. According to Parker (1926) when a bee is collecting from a purely pollen plant it carries honey to moisten the pollen and, when gathering from a plant that produces both nectar and pollen it invariably obtains nectar from the plant with which

to moisten the pollen. In our work it was found that on some days collections from apple bloom showed a comparatively high percentage of nectar carriers and, on others, a much lower percentage. Studies in nectar secretion showed that during some days in which there was a certain amount of activity of bees, the nectaries were empty or nearly so, and all bees present were gathering pollen. It was, therefore, very difficult to arrive at any average percentage of pollen and nectar collectors for the blossoming period. In regard to this problem Simmins (1904) states as follows:

"It is but seldom a bee gathers a large load of both pollen and honey on one and the same journey. A pollen gatherer will have little honey, while those carrying the most honey will seldom stay for a particle of pollen, more than what may be brushed into honey as collected. The pellets are brought in most freely up to 11 a.m. while everything is moist from the dew of night; or at any time, immediately after a shower, if warm. The honey sources of the day are about dried up by three p.m. and the bees do not often work actively after that time. As in the early morning, they then carry in much water to

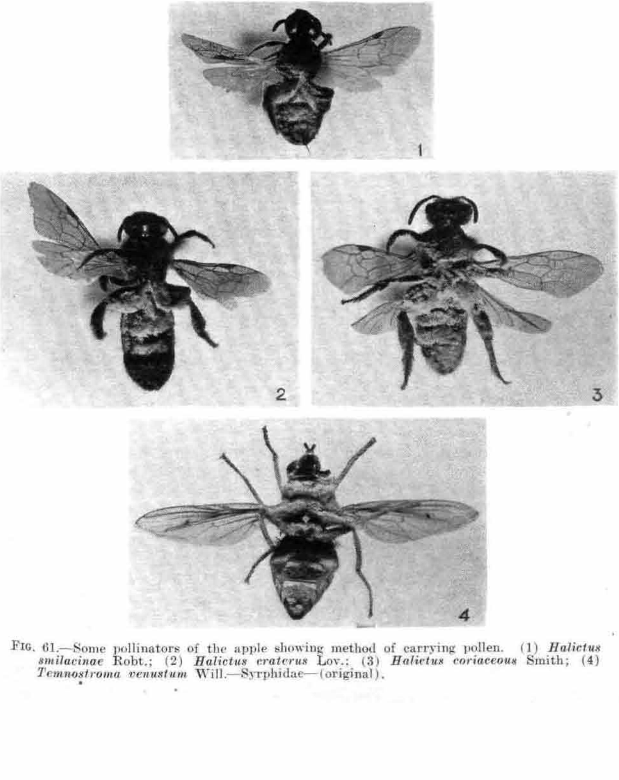


FIG. 61.—Some pollinators of the apple showing method of carrying pollen. (1) *Halictus smilacinae* Robt.; (2) *Halictus craterus* Lov.; (3) *Halictus coriaceous* Smith; (4) *Temnostroma venustum* Will.—Syrphidae—(original).

help in preparing the food for the young." Filmer (1932) finds great irregularity in the proportional number of pollen carriers during fruit bloom, which bears no relation to the total field force, the average percentage for six 3-pound, overwintered colonies being 39·6; for four 3-pound packages established on drawn comb 24·7, and for four 3-pound packages established on foundation 15·7.

Parker (*loc.cit.*) in studies of a number of selected plants records a count of 45 hive bees collecting pollen only, 24 collecting both pollen and nectar and

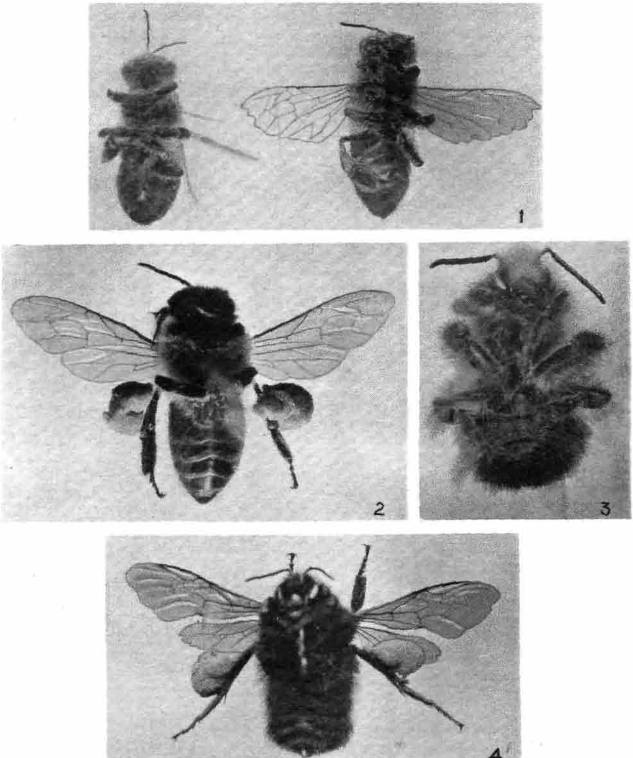


FIG. 62.—Hive and bumble bees showing characteristic methods of carrying pollen: (1) *Apis mellifica* L., showing pollen attached to hairs of body; (2) *Apis mellifica* L., with pollen baskets full; (3) *Bremus ternarius* Say, showing pollen attached to hairs of body; (4) *Bremus fervidus* Fab., with pollen baskets full (original).

31 collecting nectar only, on western crab apple. On apple this count was 22·9 and 69 respectively.

During the period of apple bloom at Ottawa in 1932, Mr. A. H. W. Birch, of the Division of Apiculture, made observations on approximately 7,000 bees entering the hives, of which only 23·57 per cent were pollen gatherers. Full

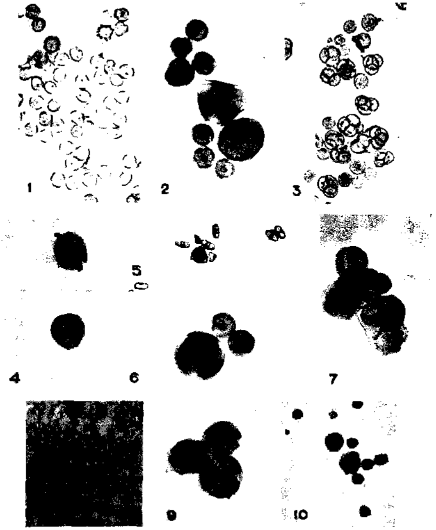


FIG. 63.—Pollen mixtures from bees: (1) *Apis mellifica* L. from *Pyrus malus* L., pollen *P. malus* and *Taraxacum;* (2) *A. mellifica* L. from *P. malus* L., pollen *P. malus* L. and *Caragana;* (3) *A. mellifica* L. from *P. malus* L., pollen *P. malus* L. and *Vaccinium;* (4) *A. mellifica* L. from *Taraxacum*, pollen *Taraxacum* and *Tulipa;* (5) *Bremus fervidus* Fab. from *P. malus* L., pollen *P. malus* L. and *Daucus Carota* L.; (6) *Bremus vagans* Smith from *Caragana*, pollen *Caragana* and *Tulipa;* (7) *A. mellifica* L. from *Taraxacum*, pollen *Taraxacum*, *Tulipa* and *Vaccinium;* (8) *A. mellifica* L. from *Spiraea*, pollen *P. malus* L. and *Spiraea;* (9) *A. mellifica* L. from *Taraxacum*, pollen *Taraxacum* and *Tulipa;* (10) *Andrena carlini* Ckll. from *P. malus* L., pollen *P. malus* L. and *Trifolium* (original).

details of this work are given elsewhere. A more careful examination of large numbers of nectar gatherers to determine what proportion of them are of value as pollinators for apple bloom would appear to be indicated.

It would not appear that we would be justified in considering more than 50 per cent of the hive bees present in the apple bloom as effective pollinators; whereas, in the solitary bees where this division of labour does not obtain, it would seem that all females captured should be counted as potential pollinators, solitary bees being mainly interested in pollen to prepare the pellets for their

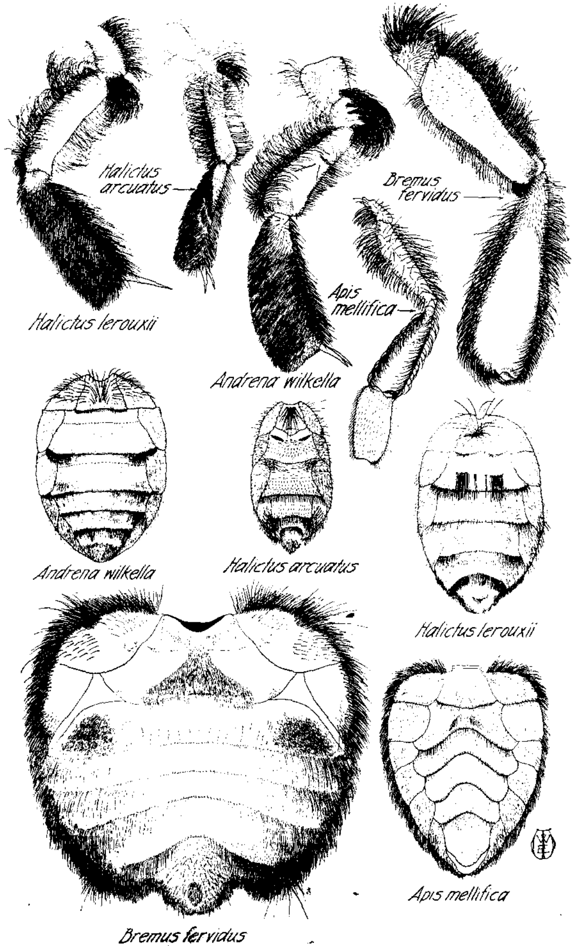


Fig. 64.— Pollen collecting apparatus of insect pollinators of the apple (original).

brood. In the case of Andrenæ, a certain proportion taken were males which are of inferior value as pollinators, but, since this proportion is small and most of our apple visitors were Halicti, this would be of little importance. Though more erratic in their flights, wild bees work the bloom with thoroughness and persistence. The pollen carrying apparatus of the hive bee, while more efficient, does not favour this species in comparison with solitary bees from the standpoint of pollination. With the latter the pollen appears to be, in general, more loosely adherent and consequently more likely to be brushed off during visits to the bloom. The pollen packed in the baskets of the hive bee is of no significance in pollination, only those grains held by the dense covering of branched hairs on all parts of the body being available. As previously indicated, solitary bees do not appear to work the same limb or tree so persistently, but it may be that this habit results in more cross-pollinations than would otherwise be the case.

8. INFLUENCE OF NECTAR SECRETION AND AVAILABILITY OF POLLEN

(*a*) GENERAL

The availability of food in the form of either nectar or pollen is recognized as having a profound effect upon the activity of bees, exhaustion of supplies being followed by a slackening off in flight. In the case of certain plants which secrete only at certain times of the day, it is possible to note a close correlation between nectar secretion and activity. In large orchard areas there would rarely be a sufficient supply of bees to exhaust the supply of nectar, and during the blossoming period, in weather favourable for flight, pollen supplies are always abundant. On several days when practically no nectar was available a considerable number of bees were noted gathering pollen. Varietal preferences of bees based on differences in nectar secretion and production of odour no doubt occur, as noted by MacDaniels (1931). The concentration of bees on varieties at optimum conditions of secretion and conceutration has also been noted. Other varieties are preferred for the comparatively large quantities of free pollen available, as in Golden Russet or Northern Spy.

Since nectar secretion was capable of measurement, however, careful records were taken over a period of several days on several varieties of apples, at Kentville, Blomidon and Scott's bay, N.S., to determine, if possible, the factors influencing nectar secretion and the influence of the latter on bee activity. So far as hive bees are concerned, nectar secretion would be expected to influence mainly the nectar gatherers, but it was considered advisable to study the secretion of nectar in relation to general bee activity and, particularly, to that of solitary bees. Unfortunately, we had no facilities for determining sugar concentration, which may well have an important bearing on attractiveness.

The records regarding nectar secretion were taken and the necessary tabulations made by Mr. Robert Ward, to whom the writer is especially indebted for his faithful attention to the details of the work.

(*b*) RESULTS AND CONCLUSIONS

A complete tabulation of all the data secured in this study would be out of place at this point. Neither is it possible to draw too definite conclusions on the basis of a partial season's work. Since the results from the different stations are in general agreement it will be sufficient for our purpose to consider in detail the results from one station only and on one variety only; viz., Northern Spy at Scott's bay.

It was found that tbe period of greatest secretion during the daylight hours was approximately 9 a.m., from which point there is a gradual decrease until

ate in the afternoon. It would appear that the nectar does not accumulate during the day, but ceases after a definite amount has been deposited in the nectary, the processes of secretion and reabsorption being apparently in equilibrium.

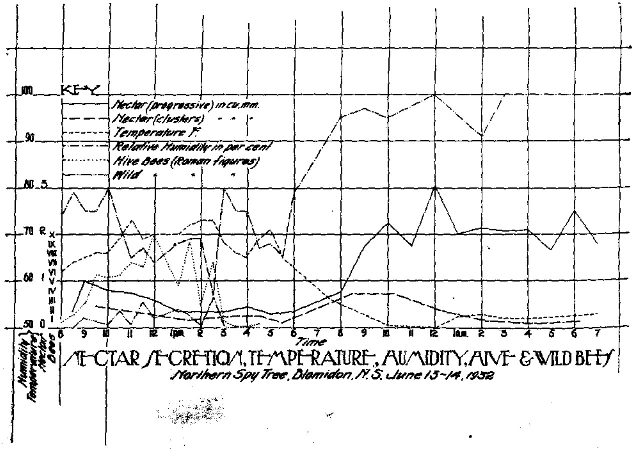
The results obtained from a study of secretion during the night varied somewhat, depending upon whether successive readings were made from different blossoms or from repeated records from all the blossoms in the same clusters, the former giving the maximum results at midnight and the latter at from 8.30 to 10.50 p.m. This would seem to indicate that nectar accumulates during the night up to a certain point, which may be determined by the evaporation rate. There appears to be a positive correlation between relative humidity and nectar secretion, but in some cases this is slight. This correlation is most apparent in the night readings.

Bee activity is so contingent upon a complex of factors operating simultaneously, that it is difficult to evaluate any one of them. It is not apparent from the data secured that the activity of either wild or hive bees is closely connected with nectar secretion. The fact that, with temperature and light conditions favourable, bees show greatest activity during the morning hours may be governed partly by the greater quantity of nectar available at that time. Considering the fact that different varieties in a mixed orchard are in their optimum condition at different periods and considering also the amount of nectar available during apple bloom in proportion to the number of bees present, and the importance of temperature, light and wind factors, it is only to be expected that any effect due to variations in nectar availability might be effectively disguised.

9. COMPARATIVE CONSTANCY OF HIVE AND WILD BEES

The following important advantage has been claimed for the hive bee:—

That the hive bees show greater "flower fidelity," that is, they tend to visit only one species of flower at a time for pollen or nectar, whereas wild species tend to visit a larger number of species.



... in relation to nectar secretion (original).

Though constancy of the hive bee in visiting blossoms of a single species has been a matter of comment since very early times, our figures based on pollen loads of all species concerned do not permit us to conclude with any degree of certainty that any of the species studied whether hive bees, Halicti, Andrenæ or Bremi, show any decided advantage over the other in regard to constancy except that, where there is a great variety of species in bloom without any one predominating, the Andrenæ observed showed least. Where a large acreage of apple is available, all forms showed a considerable degree of constancy, exceeding in all cases 50 per cent and often reaching 100 per cent, but, when abundant bloom of many different species was available, without the predominance of any one plant species, the constancy exhibited was very much less. Based on apple bloom alone, *Apis* took first place with 80 per cent of pure loads, followed by *Halictus* with 72 per cent, *Bremus* with 65 per cent and *Andrena* 57 per cent. Based on all species of bloom, *Halictus* appeared to lead *Apis* in constancy, but the difference indicated was not sufficiently great to be significant. If it were possible to express the proportion of pollen in the loads, the degree of constancy would appear greater than in percentage of pure and mixed loads, since a large proportion of the loads classified as " mixed " were made up of a great preponderance of one kind of pollen.

10. DISTRIBUTION AND CONCENTRATION

As indicated in other sections hive bees are more specialized in their habits than are wild bees, and this affects their value as pollinators, sometimes favourably, sometimes unfavourably. It has been shown by a number of investigators that hive bees possess " scouts " and that these " scouts " are able to make known to other workers the presence of food in the form of nectar or pollen. Hive bees have been repeatedly observed to ignore apple bloom near their hive to seek other more attractive bloom farther afield and, on occasion, to concentrate on favoured varieties or on varieties in a favourable condition of nectar secretion or pollen availability. Wild bees are not considered to have anything in the nature of " scouts " and hence would not be expected to have the same tendency to concentrate as hive bees, though they are certainly able to recognize and select bloom in its optimum state of attractiveness. In the orchard, however, our counts are more consistent with wild bees, even where colony distribution has been such as to secure maximum evenness of distribution of the insects. Sudden concentrations of hive bees, however, examples of which are discussed elsewhere, have occurred on a number of occasions in the course of our observations. Considerable unevenness of distribution has, however, been noted with solitary bees, the exact reason for which was hard to determine.

11. GENERAL SUMMARY

(i) The great present scarcity of hive bees in the Annapolis valley accentuates the importance of a knowledge of the native fauna concerned in apple pollination. It was found that the most important agents at the present time in apple pollination were various species of solitary bees. These bees are found everywhere nesting in the ground in roadside banks, pastures sparsely covered with vegetation, the drier parts of dyke lands, in " running dykes " and similar situations. They avoid sandy or gravelly soil in nesting and, hence, are more numerous in places near the North Mountain, Long island, etc., than in many other sections.

(ii) Observations made during the past four years indicate that in the average orchard the number of solitary bees present during bloom was about equal to the force of hive bees that would be released from one strong colony

per. acre. Nevertheless, there was evidence of a shortage of bees in certain individual orchards, and during 1932 there was an apparent general decline of about 50 per cent in the population of solitary bees. It should be noted that the three years previous to 1932 were exceptionally favourable for the increase of the solitary bee population.

(iii) Our observations indicate that, with little other bloom available, one-third of the total field force of hive bees may be found at one time in the apple blossoms. Of these not all are of equal value in pollination, since a large proportion are nectar gatherers. Solitary bees visit the blossoms mainly for the purpose of collecting pollen, which they mix with a little nectar and use for brood rearing purposes. Therefore, practically the entire solitary bee population would be expected to be potential pollinators.

(iv) The fact that hive bees only can be artificially increased and introduced at will into the orchards is a decided point for the use of hive bees. No other provision is possible against seasonal fluctuations in the normal population of solitary bees.

(v) Hive and wild bees react similarly to temperature, light, wind, humidity, etc.; but hive bees appear to work longer hours, and, while the optimum temperature for both is about the same, a larger proportion of hive bees are found at the lower temperature ranges and lower light intensities. Furthermore, the fact that hive bees will work actively near the hive during brief bursts of favourable weather, gives an advantage to orchards so supplied in years of uncertain and changeable weather during bloom.

(vi) Definite figures as to numbers of visits of wild bees are not available; but, placing the lowest possible estimate on the number of visits made by either hive or wild bees, it is apparent that a force equal to that liberated from a single, strong, overwintered colony would be theoretically capable of effectively pollinating a number of blossoms, representative of the entire complement of an acre of bearing trees, in a comparatively short period of favourable weather.

(vii) In pollen gathering habits the solitary bees are equally well adapted for pollination purposes, and, in some respects, appear to have an advantage.

(viii) Many workers have claimed a superior value for hive bees with respect to their greater constancy to the flowers visited, but we were not able to confirm this observation in our studies, the difference between *Halictus* and *Apis* not being significant.

(ix) Owing to limitations already noted, much further work must be done before many of the points raised in the foregoing pages can be regarded as satisfactorily settled.

E. UTILIZATION OF HIVE BEES AS ORCHARD POLLINATORS

W. H. Brittain and C. B. Gooderham

1. HISTORICAL REVIEW

Many workers have published data and opinions regarding the actual commercial value of hive bees for the purpose of pollinating apple orchards. A number of typical examples is therefore included, in order to give a representative picture of the present status of opinion regarding this matter.

Gates (1917) states that bees are of more value to the fruit-grower than to the apiculturist, because of their work in pollinating fruits. Many cases are cited in which absence of bees, or weather which prevented their working, resulted in poor crops. In one case, a high south wind prevailed during the blooming period, and as a result the north sides of the trees alone had a good set, as the bees worked in the shelter.

The case is cited by Weed (1918) of two orchards in Wayne county, N.Y., kept under observation at blooming time. Both had fair bloom—one had many

hive bees working in it, the other practically none. The crops were about equal in the two orchards. Other wild bees, as Bombi, Andrenidæ, Halictidæ, etc., were considered to be responsible for the pollination of the orchard which had no hive bees in it.

Sax (1922) states that good crops have been obtained in New England, where bumble bees were apparently the only pollinating agents. However, honey bees are desirable and in some cases indispensable.

According to Haseman (1922) the hive bee is the best agent for the pollination of deciduous fruit trees. Hive bees are more valuable in cool weather than at any other time because the supply of other pollinating insects is then at its lowest.

Bercaw (1924) describes experiments sponsored by the University of California at the instance of the prune growers, showing that honey bees were the chief pollinators of deciduous fruits in California. Citrus fruits are in the same class.

DeOng (1925) emphasizes the danger of relying upon self-fertilization, particularly when a single type is grown in large areas; and states that under most conditions, dependence must be placed on the aid of insects, and especially the honey bee, for pollination. Bees are said to be better adapted for pollen carrying than other insects, but some are of greater value than others. He notes that bumble bees, carpenter bees, etc., are not active early in the spring, or if so, are in such small numbers that they are comparatively ineffective as pollinators, and during the summer they have only one to six brood cycles; whereas the honey bee has twelve to fifteen broods in a summer. He points out that the workers survive the winter also, while all except the queens of the native species succumb. Another advantage of hive bees noted by this worker is that their numbers can be distributed as desired in the orchards, while the numbers of wild bees depend on the natural surroundings.

Because bees are present in large numbers in the spring, and work from morning until night and from early spring until late fall, they are regarded as the most efficient pollinators of deciduous fruits, by Davis (1926). A few instances of the value of honey bees to orchardists are given. Two hundred hives of bees were placed at one end of an 80-acre cherry orchard at Belleview, Ohio. The crop grew lighter in proportion to the distance from the hives. In another orchard the bees were all killed by foul brood, except one colony which was placed in the centre of the orchard. There was a definite fruit area about this hive, while the other trees had no crop. Orchardists are advised to have one colony for every fifty trees, and to avoid spraying at blooming time.

The importance of bees to the fruit-grower is emphasized by Hendrickson (1927) and the causes of decreased numbers of wild and tame bees are ascribed to intensive cultivation and lack of skill in beekeeping respectively on the part of fruit-growers. With regard to the distribution of bees in orchards, a case is cited in which fifteen colonies were placed on each side of a thirty-acre prune orchard. A heavy crop was borne along the edges, but in the centre the crop was very light.

According to Barclay (1928) the orchard districts in New Jersey are surrounded by an extensive trucking area, and as a result wild bees of all kinds are scarce. He states that, since 1918, the use of bees for pollinating purposes has increased steadily. One hundred colonies were rented in 1918; 1,600 were rented in 1927. Prices ranged from $5 to $8 per colony. Blueberry and cranberry growers are faced with a problem similar to that confronting the orchardists.

Marshall, Johnson, Hootman, and Wells (1929) present evidence which is considered to indicate the value of bees in orchard pollination. An 11-acre Spy orchard had never produced more than 1,500 bushels in any season from 1918 to 1926, even though it contained an apiary of 40 colonies. In 1927 pollinizing bouquets were distributed throughout the orchard, which, in that year produced

a crop of 5,200 bushels. Other examples are given. The commercial fruit grower is said to be almost entirely dependent upon the hive bee to insure pollination of his fruit, and it is stated that there are not enough bees in many orchards at blossoming time to insure adequate cross-pollination during certain seasons when the weather is unfavourable for insect activity. It is claimed that small orchards and those adjacent to uncultivated fields, woods or swamps, where wild bees can winter in satisfactory numbers, may produce crops without the addition of bees, but in most commercial orchards the chances of a good crop are increased by the addition of one colony per acre in mature orchards, or one to four acres in orchards 10 to 15 years old.

Lundie (1927) states that out of the 119 varieties of apple commonly grown in South Africa, 77 are self-sterile and the others give bigger crops when cross-pollinated. He points out that honey bees in South Africa are able to rear several brood cycles before the fruit bloom appears, and for this reason are the most valuable pollinating insects. He regards wild swarms as having some value, but not comparable to that of tended hives, because such swarms are usually weak in the spring. He contends that non-social insects are not numerous enough to be of importance in large orchards, but do some good work.

In a popular bulletin by Phillips (1930) the place of the honey bee in the orchard is discussed. Due to cultivation, destruction of both honey bees and wild bees by dusting and spraying, and to the natural scarcity of wild bees in spring, honey bees are considered to be the most satisfactory pollinating agents.

(*a*) EXPERIMENTAL USE OF HIVE BEES

During the entire course of our work, poisoning from sprays and dusts constituted a disturbing factor and rendered abortive much of the work attempted. This and other causes limited the scope of the work. Only those projects that we were able to carry to completion are reported herein.

(i) *Tent Experiments.* The best indication of the necessity for bees in order to ensure proper pollination of the apple is obtained from a study of the results of trees enclosed in tents, both with and without bees, because it is possible to control the conditions of the experiment. These experiments have been discussed in detail elsewhere, but the following tabulation is of interest in connection with the present discussion, since it emphasizes, for all varieties, the necessity of bees for pollination, as well as the primary need for a suitable supply of pollen for them to carry. It will be noted that even such a highly self-fruitful variety as Baldwin gives improved results when supplied with bee and the pollen of a self-fruitful variety. The " bouquets " used in these test were blossoming limbs of the desired varieties placed in tubs of water insid the tents; bees were placed in the orchard to provide for the open pollinate trees and abundant sources of suitable pollen were present.

TABLE No. 18.—RESULTS OF TENT EXPERIMENTS, 1929–1932

Variety	Per cent fruit					
	Effective pollinizer and bees	Ineffective pollinizer and bees	No pollinizer and bees (selfed)	No pollinizer and no bees	Effective pollinizer but no bees	Open pollinatior
Gravenstein	10·90	1·14	2·12	0·67	0·47	9
King	5·42	3·58	3·32	1·03	1·81	4
Baldwin	8·17	4·96	7·77	3·49	5·05*	10
Spy	10·05	2·70	2·00	0·85	1·20	8

*Abnormally high percentage fruit obtained in 1932, due to small number of blossoms on tree u has raised the general average for this treatment.

The velocity of the wind inside and outside the tent was taken for purposes of record and because of its bearing on wind pollination on tented trees. Considerable irregularity was noted, but the difference between tented and non-tented trees was very apparent. In order to equalize results, therefore, a draft from an orchard duster was blown through the bouquets and over the tree, the velocity being 30 miles per hour at six feet from the nozzle.

(ii) *Field Experiments.*—To secure comparable results under uncontrolled orchard conditions is impossible, because fruitfulness is due to too many factors not under the control of the experimenter. The possibilities of selfing, unfruitful crosses, poisoning of bees and many other factors, render this type of work very uncertain and unsatisfactory. Many reports of spectacular results from the use of bees are of doubtful value, as they indicate a single years' observations only and data regarding succeeding crops are rarely forthcoming. Sudden increases in the crop of individual orchards have been repeatedly observed, under conditions sometimes difficult to explain, but which were certainly not due to this particular factor. It was apparent throughout the work that the presence of an adequate supply of effective pollinizers was of prime importance and that, unless a fair proportion of the bloom present was of this kind, unfruitful crossing or selfing negatived the results of bee introduction.

Where such effective pollinizers have not been provided when the orchard was planted, they should be introduced as speedily as possible by top-working the desired number of trees. The temporary expedient of pollinizing "bouquets" consisting of limbs of the desired bloom placed in tubs throughout the orchard, has been recommended by a number of workers, but there are several disadvantages attending the practice even as a temporary measure. A great deal of labour is involved in securing the bouquets and in keeping them fresh. It is very difficult to procure bloom in such a quantity as would compare with the required number of trees in full bloom, and the chances of selfing or unfruitful crossing are greater than for fruitful crosses. Furthermore, such bouquets appear to be much less attractive than full trees. Nevertheless, in experimental work it was impossible to wait for " grafting out " operations and, for this reason bouquets were employed.

In numerous experiments with bouquets we were never able to secure sufficient to utilize them in an orchard of any size without undue cutting of the trees used as the source of the bouquets. Even when bouquets were obtained as large as possible, kept fresh and placed on small stands surrounding the trees, we could, in many cases, get little definite evidence of value from the use of such bouquets in orchards. Furthermore, counts made at the bouquets often showed few bees visiting them when masses of other bloom were available, though bouquets in full bloom, obtained from a later district and placed in orchards just out of bloom, were heavily visited. In the same orchard where negative or inconclusive results were obtained from the use of bouquets, hand pollinations with the same variety of pollen as that provided by the bouquet gave a heavy set of fruit. Our experiments were done mainly with Blenheim, a variety in which pollination difficulties are frequently experienced. By placing rings of bouquets around a group of trees, or by enclosing a row of trees with a row of bouquets, we were able, in one case, to double the set on that particular row. In most cases, however, the results were not significant and we were unable to get the spectacular results obtained by certain other workers.

The result of only one such experiment under the optimum conditions for securing such results, will be reported in detail. The experiment was conducted in an orchard of Blenheim, Stark and Mann, cross-unfruitful and self-unfruitful varieties, consisting of 17, 41 and 29 trees respectively. Hand pollination tests in 1931 indicated that a pollination problem was involved and, even in that year when Blenheim everywhere gave a crop, this orchard failed to pro-

duce. A ring of bouquets was placed about the trees so as to enclose several of each variety. Bouquets of cross-fruitful varieties were used, mainly Wagener and Red Astrachan. Owing to the weather there was no difficulty in keeping the bouquets fresh; they were visited freely by bees and, though weather conditions during the bloom were unfavourable, there was sufficient time during bloom to ensure pollination, since 50 hives of bees were placed in the orchard.

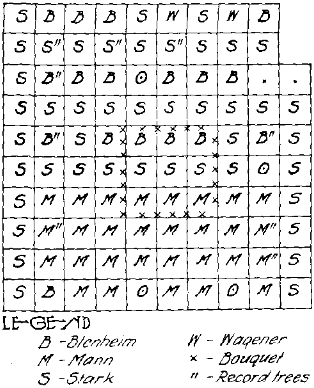


FIG. 66.—Diagram of C. Bishop orchard. Somerset, N.S. (original).

Blenheim and Mann blossomed well; but Stark, which bore a heavy crop the year before, had little bloom. The results obtained from typical trees inside and outside the ring of bouquets are indicated in the accompanying table. They indicate a commercial set on the Blenheim and a less than commercial set on Mann which, however, were in a particularly poor condition from a nutritional standpoint. The fact that the crop decreased as the distance from the bouquets increased was plainly evident.

TABLE No. 20

Variety	Position	Number blossoms used	Per cent fruit
Blenheim	Within bouquets	9,918	6·47
"	Outside "	10,000	4·33
Mann	Within "	8,060	2·30
"	Outside "	8,077	1·58

According to the owners of the orchard, the crop obtained under these conditions on Blenheim which had a full bloom, is over double that of previous years. Considering the large amount of unfruitful pollen available and the comparatively poor nutritional condition of the orchard, the results are as good as could be expected. Other experiments in solid blocks of Blenheim gave similar results on trees immediately adjacent to the bouquets, in one case doubling it as compared with the general average for the orchard.

FIG. 67.—With a full blossoming tree it requires a set of only one blossom on every fourth spur to give a commercial crop (original).

(b) WHEN HIVE BEES SHOULD BE USED

It must be admitted that, whereas the opinions of most of those who have written on the subject of the value of hive bees in orchards, appear to be strongly in favour of this practice, the tangible evidence as to their value is, as has already been indicated, rather meagre so far as apple orchards are concerned. Again it is often assumed, on the basis of little actual observation, that wild bees are "scarce." Many of the species concerned are small and inconspicuous, and we have repeatedly checked the statement " There isn't a bee in the whole orchard," only to find solitary bees present in considerable numbers.

Obviously, a survey should be made to determine the extent of the wild bee population before it can be confidently stated that they are " scarce." Unfortunately, investigations have never been carried on for a sufficient length of time in one place to determine the fluctuations in such populations that may occur from year to year; and whether, even in favoured locations, they may not, occasionally become very scarce. Generally speaking, territory with considerable waste land, rough pasture, dykes, etc., will support a considerable bee population. The difference between certain stations in the middle of the Valley and others near the North Mountain is quite marked. Even in orchards wholly or partly in sod, there are sometimes places favourable to the nesting of wild species.

On the other hand, certain soil types and intensive clean cultivation, with an absence of rough land or other favoured nesting places may possibly result in an actual scarcity in all years, as has been claimed by some workers. In other cases, unfavourable weather, natural enemies or other factors may deplete the native fauna. Under such conditions there would be no alternative to supplying the necessary number of hive bees as a matter of orchard routine. Our own observations in four years out of five, indicate that there was an adequate population of wild bees to produce a satisfactory set in most orchards studied. However, in the fifth year, there were extremely unfavourable conditions prevailing during the bloom of certain varieties. Under these conditions, a much heavier population of pollinators than would be necessary in a normal year, would be a decided advantage. Fruit setting on many varieties was very light, but very satisfactory sets were obtained even with short periods of exposure, where hive bees had been properly distributed in adequate numbers. The tendency of the bees to exhibit greatly increased activity, especially near the colonies, during a warm, sunny period following one of confinement, helped to bring this about. The provision of hive bees, therefore, in any commercial orchard is a measure of insurance against such a condition, and should be so regarded. When general unfavourable conditions prevail, this must be compensated for by a force capable of effecting pollination in limited periods of favourable weather. The question of whether or not such provision shall be made, resolves itself into a question of whether the cost of the operation will be more than compensated for by the expected benefits.

2. PROBLEMS INVOLVED IN COLONY DISTRIBUTION AND NUMBER

(a) THE TIME NECESSARY FOR POLLINATION

The amount of pollination that takes place varies with the strength of the colonies and with the length of time available for them to do their work. With favourable weather, a relatively small population may accomplish the same result as that obtained by a much larger force in a short period. In considering this question, the amount of pollination secured in definite periods of time by a population of given strength is of value.

At Kentville in 1931 we attempted a small experiment to determine the length of time actually required for the pollination of three Northern Spy trees

covering them with tents and opening one side of the tent for 1 hour, 5 hours and for one day respectively. Unfortunately, the bee population at this station during the period in question was very low, viz., only ·028 per minute—much too low on which to base any calculations. In view of this fact it is not to be expected that the results would be very consistent. However, as indicated by the accompanying table there is a great difference between the tree that was exposed during bloom and those exposed only for a few hours. In interpreting results from work of this kind it must be borne in mind that the set of fruit obtained is by no means an accurate gauge of the effective bee population, because double visits, unfruitful crosses, and selfing must be taken into account. There is also a very definite limit to the number of blossoms that can set fruit and many blossoms that are pollinated can never produce mature fruit. Therefore, figures showing the set obtained from a given number of blossoms exposed to pollination for a definite time can have but limited value, though it is of interest to study the results obtained, particularly from exposures of short duration, since, in these cases, the blossoms pollinated were not in excess of the number that could set under normal conditions.

TABLE No. 21.—EFFECT OF LENGTH OF EXPOSURE ON POLLINATION

Tree	Time of exposure	Number of blossoms counted	Per cent fruit
1	1 hour	2,553	0·35
2	5 hours	2,641	0·15
3	All day	2,938	1·29
4	Throughout bloom	2,552	5·72

NOTE.—*Total acreage of orchard 70; number of colonies 37.*

It will be noted that the tree exposed throughout the day shows a higher percentage than the other two, but the tree with a five-hour exposure shows a lower percentage set than the one exposed for only an hour. These numbers were so low that individual differences in the tree, its location, number of blossoms and the error inherent in such a small scale experiment, might easily account for the differences. The experiment shows that, under these particular conditions, adequate pollination was far from being obtained from a full day's exposure.

During 1932 further work was projected in which it was planned to expose whole trees and individual limbs to pollination by bees for varying periods of time, viz., 1 hour, 3 hours, 1 day, 2 days, 3 days, etc. Unfortunately, weather conditions interfered seriously with the experiments. In some cases the short exposures were carried out under ideal conditions, but the weather then became wet and cold and all activity ceased for days at a time. The result was that an intended one-day exposure ran into several days, during which no bees were present. When conditions again became suitable for flight, they were in some cases more and in some less favourable than for the shorter exposures, with the result that, during the longer exposures, there were in some cases actually a lower number of bees available than during the shorter periods. Interpretation of results therefore becomes very difficult. Bearing in mind these points, the results as indicated in the accompanying table, show no more irregularity than would be expected from the nature of such tests. In this tabulation we have calculated the number of "effective hours" that the blossoms were exposed. This was arrived at by taking the total number of *ten-minute periods* during the time of exposure of that particular bloom, when any number of bees, however small, was found at work in that particular orchard. This figure, in turn, was divided by six. Since, however, the number present during the period of exposure was an equally important factor, we have also calculated the average number of bees taken per ten-minute count over the same period.

Allowing for the irregularities inherent in such tests, and without attempting to carry conclusions from such figures too far, we find that the set obtained in as short a period as one hour was sufficient to give a commercial crop in the case of Gravenstein, and that the set obtained in five hours and upwards of effective exposure, with suitable conditions for good activity of the bees, in Gravenstein and King was great enough to require thinning. Had the entire tree been exposed in McIntosh, greater sets undoubtedly would have been obtained on the tented trees, since these showed a set on the exposed side noticeably in excess of that obtained on the unexposed side. The comparatively low sets of fruit on all exposures in the case of Blenheim were obtained in an orchard in which cross-unfruitful and self-unfruitful varieties were mixed, viz., Stark, Mann and Blenheim, and was one in which poor crops were the general rule. Wagener and other bouquets were supplied, but this, undoubtedly, did not prevent a great deal of unfruitful cross- and self-pollination.

Allowing for the proportion of nectar carriers, duplicate visits, unsuccessful crosses, etc., these figures do not appear inconsistent with the information obtained from other sources.

TABLE No. 22.—TABLE SHOWING INFLUENCE OF LENGTH OF EXPOSURE ON POLLINATION

Variety	Number of blossoms used	Number of effective hours (*) of exposure	Average activity per 10 minutes during period of effective exposure	Per cent set obtained	Per cent fruit after July drop
Gravenstein	1,599	nil	....	11·69 (²)	1·63
"	2,267	1	16·78	9·97	3·97
"	2,312	5	15·97	18·47	7·01
"	2,382	$8\frac{1}{3}$	12·35	11·92	6·76
"	2,547	$14\frac{1}{2}$	8·01	20·77	10·91
"	2,658	$23\frac{1}{3}$	5·31	18·59	9·63
"	2,141	Duration of bloom.	....	26·86	10·28
King	909	nil	....	1·36	0·25
"	1,556	1	2·04	5·98	1·99
"	1,631	$4\frac{5}{6}$	1·03	27·16	6·72
"	1,363	$11\frac{1}{3}$	2·79	25·61	10·93
"	2,086	$22\frac{1}{3}$	5·38	39·26	7·19
"	1,247	$23\frac{1}{2}$	5·05	28·63	9·70
"	1,393	Duration of bloom.	....	19·02	11·84
McIntosh (¹)	3,325	$\frac{5}{6}$	2·00	4·69	3·91
"	2,496	$2\frac{1}{3}$	3·44	6·86	5·61
"	2,881	$4\frac{2}{3}$	3·29	6·98	5·73
"	2,311	Duration of bloom.	....	13·85	8·57
Blenheim	1,174	nil	....	0·085	0·085
"	1,007	1	13·1	1·19	0·10
"	1,268	$4\frac{1}{2}$	2·12	0·47	0·08
"	1,401	$5\frac{1}{3}$	1·98	0·21	0·21
"	1,870	Duration of bloom.	....	7·54	6·26

(*) An *effective hour* represents 6 ten-minute counts, during which the blossoms were exposed and during which some bee activity was actually observed in the orchard.
(¹) In tent.
(²) High original set probably produced by selfing from rubbing about inside the bag.

(b) TYPE OF COLONY REQUIRED

(i) *Historical.* Most writers favour the use of strong overwintered colonies for pollination purposes. Some, however, recommend the use of package bees when others are not available, while a few go so far as to claim that certain types of packages are preferable and have a larger field force than overwintered colonies. The following recommendations may be regarded as typical:

DeOng (1925) recommends that bees which are to be used for pollination should be in good condition and strong in numbers in the spring, though, for purely honey producing hives, large numbers in early spring are not so necessary.

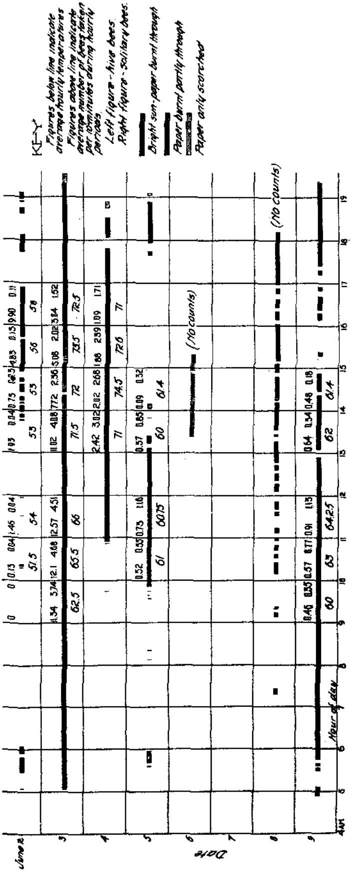


FIG. 69.—Chart showing conditions of sunlight during period of exposure of blossoms to bee activity, Long island, N.S. (original).

Philp and Vansell (1932) in connection with the use of bees for pollination, point out that only strong colonies will prove of much value during the early spring, when a large number of bees are required in the hive to maintain the

Phillips (1930) advises that strong colonies only should be used in the orchard, since a hive with twelve frames of brood is four times as valuable as one with six frames of brood. For this reason he considers that the colony should be in two hive bodies. The strength of the colonies is regarded as more important than their number by this worker, since powerful colonies send out proportionately far more bees than weak ones, and also start flight sooner. While no hard and fast rule is laid down, the author suggests one twelve-frame colony to each four acres, or one six-frame colony per acre.

Murneek (1930) considers that a good colony should contain at least five pounds of bees, or approximately 25,000.

A comparison was made by Hutson (1928) between the numerical strengths of package bees and overwintered colonies by weighing the entire colony, removing the bees, then weighing the empty hive—ten being used in each case. On the basis of 5,000 bees to the pound, the bees in ten hives were said to comprise 108,750 individuals as compared with 150,000 for ten 3-pound packages—an advantage of 40,000 over the overwintered colonies. It was also shown that overwintered colonies were very unequal in strength. On the basis of the foregoing, it was concluded that 3-pound package bees were superior to overwintered colonies on the score of strength and uniformity, thus giving the orchardist an opportunity to secure better distribution in his orchard.

Other New Jersey experiments (1929 and 1930) showed that combless packages, regardless of size, were not comparable in value to overwintered colonies; and that the orchard packages, while superior to combless packages, were also inferior to overwintered colonies.

Filmer (1931 and 1932) has presented some evidence regarding the value of different types of colonies. The packages used were established three weeks before the counts were made, which were carried out, presumably, during fruit bloom. Packages established on foundation were fed 40 pounds of "one to one" sugar syrup. From a study of the data presented in this paper the following may be gathered:—

1. Total bees show no correlation with total pollen gatherers which vary greatly in different types of colonies.

2. Total bees for overwintered colonies and for packages supplied with foundation only, is the same; for 3-pound packages on drawn comb it is less.

3. Considering the different weights of colonies in relation to total activity, 2- and 3-pound packages seem little, if any, inferior to 6-pound packages of the same type. In fact the 6-pound package on drawn comb shows less activity than the corresponding 2-pound package. The wrapped 3-pound package showed only 50 per cent of the activity of packages supplied with drawn comb, and 43 per cent of 3-pound overwintered colonies.

4. The average pollen gatherers liberated from 2-, 3- and 6-pound packages, whether those supplied with drawn comb or with foundation alone, showed little significant difference, but were decidedly less efficient than overwintered colonies while wrapped packages showed negligible efficiency.

5. Total pollen carriers are greatest, in all cases, from the overwintered colonies; for 3-pound packages the count strongly favours the packages supplied with drawn comb in one case, with result about the same in the other.

6. On the basis of the data secured, the author considered that there was a relation between the brood content and total activity in colonies of the same weight, with bees on foundation showing a greater activity in relation to brood area than those on drawn combs. He considered that the figure for total bees was of more value than that of pollen carriers alone, owing to the great variability in numbers of pollen carriers.

Farrar (1931) has brought forward evidence bearing on the question of the *relative value of overwintered colonies as compared with package bees.* He notes that considerable emphasis has been placed upon the necessity of designing a "colony unit" that the fruit grower can use without a knowledge of bees and with a minimum of handling. He points out that, upon this development, depends the question of whether to stimulate practical beekeeping or to depend upon packages. He considers that the orchard yield is the result of too great a complex of factors to be a suitable criterion of the colony's efficiency in pollination, but the degree of pollination should be proportional to the number of bees visiting the blossoms. He assumes that the colony unit furnishing the greatest number of field bees per minute will provide visits to the greatest number of blossoms, and therefore, accomplish the greatest results in pollination. He describes the results of two years experiments at Amherst, Mass., on the number of bees furnished during bloom by (1) package bees, (2) nuclei, and (3) overwintering colonies, which indicate a pronounced advantage in favour of the last. In a normal season (1929) the overwintered colonies furnished 8 to 20 times as many bees per minute as 3-pound packages or 3-frame nuclei, when the bees *were allowed to fly from their shipping package.* In 1930, under abnormally favourable conditions, normal overwintered colonies showed a decided advantage over 5-pound packages, and these in turn over smaller packages. The writer concludes that where colonies cannot be secured, strong packages should be obtained a week in advance of expected blooming date, installed in hives—preferably on drawn comb—and fed, in order to insure immediate establishment of the brood nest.

Woodrow (1932) has presented some valuable data respecting the relative value of different types of colonies using the method of Farrar (*loc. cit.*), the counts being made during apple bloom. Records were based on the number of bees leaving the hive, made up of 3 pounds of adult bees, one 3-pound package on comb foundation, and one 3-pound package in its shipping cage. The second was similar to the first, but consisted of 5-pound units. The third group consisted of unmodified overwintered colonies, one with 3 frames of brood and 1·63 pounds of bees; one with 7 frames of brood and 4·38 pounds of bees; and one of 16 frames of brood and 8·25 pounds of bees.

Flight from 5-pound units exceeded those from 3-pound units, though not in proportion to the strength of the colonies. A study of the flight figures showed that, in general, at any given temperature, the flight of any colony was roughly *proportional to its strength;* but the weaker colonies flew less freely at the lower temperatures and more freely at the higher temperatures. It is concluded from the results of these studies, that strong overwintered colonies are superior to package bees, but that if only weak colonies are available, 3- or 5-pound packages are more desirable, since these can be obtained for the same price. In this work the total number of bees issuing from the hive was used with no distinction between pollen and nectar gatherers.

(ii) *Observations on Strength of Different Types of Colonies.*—At Ottawa in 1931, four overwintered colonies of average strength were measured for brood, potential force in bees, and total force. The results are indicated in the following table:——

TABLE No. 23.—STRENGTH OF OVERWINTERED COLONIES MAY 6, 1931

Colony number	Brood in square inches	Potential force of bees (*)	Weight of bees		Total force in bees
			lbs.	oz.	
313	650·52	16,260	3	11	18,437
316	805·38	20,134	5	11	28,437
327	890·03	22,250	5	12	28,750
320	725·90	18,147	4	4	21,250

(*) [illegible]

The above table shows that all overwintered colonies contained a stronger force of bees than did the 2-pound or 3-pound packages which arrived May 5, though definite figures for the latter are not available. Furthermore, all were stronger than 3-pound packages, and two of them stronger than 5-pound packages, and in addition all contained brood, which the packages received did not. The total force and the field force of the same colonies were taken during apple bloom as indicated in table No. 24.

TABLE No. 24.—STRENGTH OF OVERWINTERED COLONIES DURING FRUIT BLOOM, 1931

Colony number	*Brood in square inches*	*Potential force of of bees*	*Total force in bees*	Field force
313	1246·18	31,154	25,937	16,875
316	1279·56	31,989	31,875	14,062
327	1262·88	31,572	28,750	18,750
320	1130·76	28,269	21,875	10,937

The above were actually measured by weight and the figures based on 5,000 to a pound.

It will be noted that the field force of each of the overwintered colonies alone, exceeded the total force of bees in a 2-pound package while two of them exceeded a 3-pound package.

The colony strength, and more particularly the strength of the field force, is a most important consideration in the use of hive bees for pollination purposes. Our own information indicated that the working force is much greater, both actually and proportionally, in a strong colony than in a weak one. It appears that not only do more bees leave the hive, bnt they make longer flights and will work when weather conditions are less favourable. These facts were very apparent throughout the entire investigation. Furthermore, anything that tended to weaken the colony, such as persistent unfavourable weather and lack of stores resulting in a break in brood rearing, or cases of poisoning from sprays or dusts, quickly reduced the activity noted in the orchard. Beekeepers ordinarily do not depend upon apple bloom for a surplus of honey, but are content to have their colonies at the peak in time for the clover flow. For apple pollination purposes this is not sufficient and special means must be taken to get the colonies into optimum condition by the time the apples blossom.

(iii) *Experimental.*—In 1932, it was decided to make a comparison of th performance, during pollination, of the different types of colonies. Unfortunatel the overwintered colonies were extremely weak and, owing to unfavourabl weather, the packages, instead of increasing in strength, actually dwindled i numbers of individuals. In the test there were four overwintered colonies an two each of 2-pound, 3-pound and 5-pound packages. The latter were receive on April 26 in excellent condition.

They were released on drawn combs as soon as they arrived, the weath being very cool, and some rain mixed with snow was falling. The queen accon panying one of the 3-pound packages was found dead, but was immediate replaced with a queen from another package. The overwintered colonies th were to be used as checks against the packages were still packed in their wint cases. Therefore, the package bees were released into protected hives to ma conditions comparable.

On April 29, the force of bees in each of the overwintered colonies w weighed and calculated on the basis of 5,000 bees to the pound. The results w

Colony number	Weight of bees		Total force	Colony number	Weight of bees		Total force
	lbs.	oz.			lbs.	oz.	
241	2	14	14,375	240	2	7	12,187
287	1	7	7,187	257	2	4½	11,406

Although the colonies selected were of good average strength for the season, the above figures show that they were very little stronger in bees than normal 2-pound packages, and weaker than the 5-pound packages. The colonies, however, already had brood in their hives, some of which would emerge before the apple bloom opened, while the packages had none.

On April 30, this brood was measured and found to be as follows:—

Colony numbers	241	287	240	257
Square inches of brood	417·02	270·37	441·77	408·37
Potential force in bees (*)	10,425	6,759	11,066	10,209

(*) The potential force in bees represents the number that would emerge within the next 21 days.

On May 19, two apple trees in the bee yard were in bloom but none had opened in the main orchards. Another measurement in bees and brood was *made on this date and this is shown in table 25. The field force of the colonies* was not determined at this time.

The figures in table 25 show that all four overwintered colonies had gained in strength both in bees and brood since the counts of April 29 and 30; but the gain in bees in colonies 240 and 257 was very slight. It will also be seen that all packages were reduced in strength of bees, the greatest reduction in each group equalled 46·88 per cent for the 2-pound packages, 47·92 for the 3-pound packages and 36·25 for the 5-pound packages. Even with this loss the 5-pound packages still had a larger force of bees than the overwintered colonies, at the commencement of apple bloom. It should be pointed out here, however, that because of poor wintering and heavy dwindling during the early spring, the overwintered colonies were much weaker in 1932 than they had been for the past 16 years. On the same date in 1931 four average colonies contained an average of 5 pounds 6¾ ounces or approximately 27,109 bees. It will be seen, therefore, that the comparison was made under abnormal conditions, affecting the overwintered colonies particularly, though as noted already the packages were considerably weaker than their designated strength.

On May 20, the day after the measurements shown in table 25 were taken, it was estimated that about 5 per cent bloom was open in the main orchards.

TABLE No. 25.—TABLE SHOWING THE APPROXIMATE NUMBER OF BEES AND THE AMOUNT OF BROOD IN OVERWINTERED COLONIES AND PACKAGES ON MAY 18-19, 1932.

Colony number	Overwintered colonies				2-pound packages		3-pound packages		5-pound packages	
	241	287	240	257	305	319	211	309	333	334
Brood in square inches	1,090·50	610·64	878·47	829·74	541·14	466·50	738·85	727·67	768·67	736·66
Potential force in bees	27,262	15,266	21,962	20,743	13,528	11,662	18,471	18,192	19,217	18,416
Total force of bees in colonies	16,250	9,062	12,812	11,562	6,250	5,312	7,812	11,562	19,062	15,937

The apple bloom lasted for about 12 days, as it was practically all gone on May 31. No further measurements of bees or brood were made, but counts of bees returning to the hives were made for 2 and 4 minute periods whenever weather conditions permitted during the time of bloom, according to the trapping method devised by Farrar (1931). During the period under review records

of the activity of over 7,000 bees were made. The results were averaged to show the comparative number per minute of total bees and pollen gatherers liberated by each type of colony. These data are presented in table 26.

TABLE No. 26.—NUMBER OF BEES LIBERATED PER MINUTE FROM DIFFERENT TYPES OF COLONIES

Type of colony	Average pollen gatherers liberated per minute	Average total liberated per minute	Average total force in bees	Average potential force in bees
Overwintered	8·46	35·89	12,421·5	21,308·25
2-pound package	2·11	6·52	5,781	12,595
3-pound package	8·51	31·56	9,687	18,663
5-pound package	5·56	38·20	17,499·5	18,816·5

This table indicates little significant difference between the different types of colonies, except that the 2-pound packages are much inferior on all counts. The fact that the 5-pound packages, though stronger in field force and in total numbers liberated, are lower in pollen gatherers, may or may not be significant. That the potential force of the 5-pound packages is little different from that of 3-pound packages, in spite of their greater force of bees at this time, is worthy of note. The obvious weakness of the overwintered colonies, averaging only about $2\frac{1}{4}$ pounds, makes the data worthless as an indication of the performance of strong colonies. Nevertheless, the figures are presented for what they may be worth. Since, for both 2-pound and 3-pound packages the total force was less than the field force for a good overwintered colony, the superior value of the latter, for pollination purposes, would appear to be obvious.

(c) FLIGHT AND CONCENTRATION OF BEES

(i) *General.*—A great deal has been written regarding the distance of bee flight and the problems involved in the point at which maximum concentration occurs. It is usually stated that bees will fly a mile or two from the hive for nectar or pollen and even much greater distances have been recorded. The maximum distance bees will fly is determined by many factors, some of which are considered in the following pages.

Certain workers appear to believe that there is a point located at a definite distance from the hives, at which the greatest concentration of bees will take place. Hutson (1926) considers that this point is 15 feet from the hives, gradually diminishing as the distance increases, and that this, at least in certain cases, can be definitely correlated with the set of fruit obtained. On the other hand, many workers contend that bees tend to concentrate at a much greater distance than stated by Hutson. For example, MacDaniels (1931) describes experiments in which it is shown that bees working out of the hive do not stop close to the hive, but rather go directly to some distant spot. It was further concluded by this worker that the placing of colonies of bees with relation to the varieties to be pollinated is of less importance than the position of the pollen source in relation to the trees to be pollinated. Our counts and observations gave no encouragement to the belief that there is a definite mathematical point at any certain distance from the colonies at which maximum concentration will occur. There is, however, considerable evidence supporting the contention that the optimum working distance is not necessarily close to the hives. In this connection, observations made at Coaldale, Alberta, are of interest. On a fine bright day, in an apiary located on the edge of an alfalfa field, with nectar secretion abundant and great activity at the hives, the bees were going some distance for their supplies and a search of the particular field in which the hives were located showed only an [illegible]nal bee in the blossoms, though more distant fields were freely visited.

It would appear that, while the bees are, in general, found in greatest numbers near the hives, the distance of flight and the point of maximum concentration are variable and are conditioned by a number of factors of which (i) the condition of bloom, (ii) varying varietal attractiveness, (iii) the amount and mass of bloom available in relation to the bee population, (iv) the availability of other kinds of bloom, (v) the physical features of the area concerned, (vi) the prevailing weather conditions, (vii) the position of the colonies, and (viii) the habit of bees of working in a limited area, are a few of those that must be taken into account. These are discussed in the following sections.

(ii) *Condition of Bloom.*—The condition of the bloom, particularly with regard to nectar secretion and the availability of free pollen, evidently has an influence on the activity of bees on that particular variety. This was very noticeable throughout the course of our observations. What appears to be a good example of this fact is recorded in our notes for 1930. The observation was made on Long island where an apiary of 25 strong colonies was placed just north of an orchard in full bloom. Other orchards, to an extent of about ninety acres, extended westward for a distance of two miles, there being no orchards on the east. Four men stationed in the orchard adjoining the colonies took observations throughout the day, but recorded only a negligible number of bees. During the afternoon two men scouted the entire island examining, besides apple, the blossoms of oak, rhododendron, blueberry, horse chestnut, dandelion, clover, Siberian pea, star of Bethlehem, plum, Labrador tea, lilac, mountain ash, etc., without finding any bees. Returning to the apiary, where the bees were still working actively, a flight of bees could be seen flying westward. This line of flight led to a back orchard of Ben Davis trees in full bloom, on an adjoining farm about $\frac{1}{4}$ mile distant from the colonies.

Upon approaching this orchard a strong aroma of apple blossoms and a distinct hum of bees could be detected, at a considerable distance from the trees. The first two counts, begun at 4.20 and 4.30, gave counts of 39 and 23 respectively, and the blossoms were obviously swarming with bees. This appeared the more remarkable as the sky had become overcast with heavy clouds, though the temperature registered about 76° F. In the intervening rough pasture between the apiary and this orchard, bees were observed on rhododendron and blueberry.

The next day bees were still abundant in this orchard, but, unlike the day before, were much more evenly distributed, and also in the orchard contiguous to the apiary. They were even found in measurable numbers in an orchard $\frac{1}{2}$ mile west, and small numbers were taken on buttercup, dandelion, oak, and chokeberry, the weather, like that of the previous day, being generally quite favourable for flight and activity.

(iii) *Varietal Attractiveness.*—A serious attempt was made to determine whether or not different varieties of bloom vary in their attractiveness to bees. Certain varieties that show few bee visitors on certain days, at others will be found to have many such visitors for reasons indicated in the preceding section. It is, therefore, dangerous to draw too sweeping conclusions without a great many careful observations extending over the entire blossoming period. We are satisfied that some varieties are more attractive than others; but definite proof is difficult, owing to the fact that varieties cannot be compared on an equal basis—no two being in exactly the same condition of attractiveness with respect to nectar secretion, etc., when counts are taken—and varying weather conditions make observations under identical conditions impossible. At the same time, certain varieties are outstanding in this respect, notably Gravenstein, which always gave large counts when in proper condition. The fact that few other varieties are open when Gravenstein is in bloom would tend toward a greater concentration on this variety. Gravenstein has also a showy blossom, comparatively good

nectar secretion and more pollen than most triploid varieties. Golden Russet is another variety that seems to be favoured by both wild and hive bees and, with both these varieties, blossom visitors seem to persist throughout the bloom to a greater extent than with some others. Though Golden Russet has a much less showy blossom than Gravenstein it produces an abundance of pollen and, hence, is popular with pollen gatherers. Without much more careful work, however, it is not possible to be more definite regarding attractiveness of varieties. It is worthy of note that certain varieties, *e.g.*, Blenheim and Stark, seem to have greater difficulty in getting cross-pollinated than other equally self-unfruitful varieties, *e.g.*, Spy and Cox Orange, under very similar conditions. The former two varieties furnish comparatively small quantities of pollen, while the latter are notable for the comparatively large amounts that they produce; this may affect the number of insect visitors.

(iv) *Effect of Masses of Bloom.*—The foregoing sections emphasize the important effect of the condition and nature of bloom in attracting bees. The attractiveness, at certain periods of bloom of an orchard of Ben Davis trees was particularly mentioned. Other Ben Davis trees, as well as those of other varieties in a similar condition of bloom, were present in the orchard contiguous to the apiary in question, though not massed to the same extent. The effect of masses of bloom in a correct condition to attract bees has been noted on other occasions. One orchard in which bees were placed for two different years was situated at the base of the North Mountain and consisted of moderate sized trees, mostly Baldwin, Stark and Blenheim. This orchard had been heavily pruned and there was not present any great mass of bloom at any one time. Seven colonies were present in the orchard which was of seven acres in extent and, though we now know that this was insufficient for an area otherwise totally devoid of bees, the fact that on many visits we could rarely find any bees whatever in the bloom, was somewhat puzzling. During one of these visits in which no bees could be detected, though considerable activity was observable at the hives, an orchard $\frac{3}{4}$ of a mile away was found to contain considerable numbers. The second orchard was below the level of the first, was unpruned and generally uncared for, but presented dense masses of bloom which gave off an aroma distinctly noticeable to one passing along the adjoining road. Varietal attractiveness may also have been a factor in this particular case. The greater attractiveness of larger masses is also evident in the difficulty, sometimes experienced, of getting bees to visit orchard bouquets, since they definitely prefer to go to the greater masses of bloom, other things being equal.

(v) *Availability of Other Bloom.*—Fortunately, since apples do not appear to be as attractive to bees as many other species of plants, there are not usually available at blossom time, other large sources of pollen or nectar. However, there are a number of species of plants present in smaller numbers. On many occasions, when it was difficult to find bees in the apple bloom, their presence in large numbers on strawberries, Siberian pea, dandelions, etc., could be readily detected. On one occasion, when careful search failed to reveal bees in appreciable numbers more than a quarter of a mile from the apiary on apple bloom, they were counted in large numbers on a clump of rhododendrons one-half mile away. In this connection another observation is of interest. An apiarist at McBride, B.C., was the only one keeping bees in the district. Bees from this apiary were noted working in a field of sweet clover four miles from the apiary, though an abundance of alsike and Dutch clover was available in the intervening territory. In districts in which little but apple bloom was present, the same number of colonies should obviously give a greater field force for apple pollination than in districts in which a variety of attractive bloom was present. Apple is certainly not the most-favoured plant; dandelions, rhododendrons and other plants available during apple bloom being apparently preferred under ordinary

conditions. Hence, the more of such bloom in a given locality, the less bees would there be available for apple pollination.

(vi) *Physical Features.*—The presence of hills, ravines, strips of woods, etc., frequently affect the flight and concentration of bees used for pollination purposes. One apiary, situated at the north of a large orchard, has a steep bank at the rear. The result is that the greatest numbers of the field force from this apiary fly due north across a meadow and a stream and work on the apple bloom in the orchards about a mile away. It is difficult to predict how bees will work in broken territory, but the influence of factors similar to those mentioned above, must be taken into account in deciding how bees are to be placed in the orchard.

(vii) *Weather Conditions.*—The effect of weather conditions on flight and concentration have been discussed at length elsewhere. Inasmuch as unfavourable weather limits the length and duration of flights, it is obvious that the hives should be so distributed about the orchard as to ensure proper pollination of all trees in times of unfavourable weather. Observations, made in 1932 particularly, substantiate the observations of other workers that, at such periods, there is greater activity near the hives; and that in brief periods of fine weather there is a tendency to restrict flight and activity to points not far distant from the colonies.

(viii) *Area of Activity.*—A factor that deserves consideration at this point is the habit of bees of working in a limited locality. It is the testimony of a number of careful students that pollen- or nectar-gathering over an area is not indiscriminate; but that bees tend to go to the same place and return to it, trip after trip, until supplies are exhausted. The fact that pollination is usually heaviest on the side of a tree next the pollinizer and that the effect is lost a very few rows away has been often noted.

Minderhoud (1931) reviews the observations of other workers in this field and presents his own experiments with marked bees on the flowers of *Taraxacum officinale* Weber, *Trifolium* sp., *Cruciferæ,* etc. He considers that his data warrant the following conclusions: In visiting low growing plants and in the absence of a strong wind the honey bee will for a long time visit one particular place, the area of which does not ordinarily exceed 10 by 10 metres. Under such circumstances, its successive visits are to flowers not farther apart generally, than one metre. He concludes that one can only expect to get full benefit from bees, when different pollens are available to them, within a small radius. Why this should be so is suggested by studies by Von Frisch (1924), which indicate that odour from the scent glands of the workers of a given colony, impregnating the spot visited, acts as a lure to other workers from the same colony, but not for workers from another hive. Bonnier (1906), for example, marked all the bees he found visiting a five-metre strip of buckwheat, and the next day found only marked bees visiting the strip.

On several occasions during our experiments, certain colonies have shown very severe poisoning, while others have shown little or none. A good example of this was in 1929, when no severe poisoning could be detected in 49 colonies placed in an orchard, but one colony showed poisoning of the most severe type. It seems difficult to explain this fact other than on the assumption that the bees from this particular colony secured poison from a common source. As a matter of fact, a small plot not far from this hive had been dusted with sulphur lead arsenate dust which may have furnished the source of the poisoning Similar evidence, with respect to the gathering of certain kinds of nectar by particular hives, will occur to any experienced beekeeper.

(ix) *Amount of Bloom Available in Relation to Population Present.*—The amount of bee pasturage available in a given area, relative to the population

present, has a very important bearing on the distance of flight and the point of maximum concentration. Thus, in a territory with small scattered orchards and little other bloom available, we would expect them to go farther afield than in a densely orcharded area during the period of bloom. Evidence is available from Fort Vermilion, Alberta, vouched for by the Superintendent of the Experimental Station and a Hudson Bay Company official at the place, that bees from the Experimental Station, the only hive bees in the entire area, were taken seven miles away at the Hudson Bay Company office. This, however, represents a condition quite different from that in the territory in which our studies were made, where large blocks of orchard were everywhere present. Our counts indicate that, up to a certain point, when the apiary strength is increased, the bees range farther afield, as was the case in Somerset in 1932, when 50 strong colonies were placed in an orchard with 44½ acres of orchard within a quarter-mile radius and 137 acres within a half-mile radius. Here, bees were readily detected in appreciable numbers a mile away. Flight and concentration are, therefore, affected by the number and strength of the individual colonies and by the number of colonies available in any one place. This fact is important when considering the number of colonies required to secure pollination in any given fruit growing area.

Various recommendations are made as to the number of colonies per acre required to ensure adequate pollination of apple orchards. The majority of these vary, from one colony to each four acres of young bearing orchards, to one colony per acre for large trees. A few typical references at this point will suffice for our purpose.

Hooper (1929) recommends one hive of bees to each acre of fruit trees, especially in a district unsuitable for wild bees. DeOng (1925) considers one strong hive to the acre as a sufficient pollinating force. Murneek (1930) believes that one colony to every three or five acres will be sufficient for a young orchard that has just come into bearing, but that older orchards may need a hive per acre. It is contended by Philp and Vansell (1932) that the usual recommendation of one hive per acre is more than necessary under some conditions, but weather conditions so affect results that more would often be justified.

Certain recommendations would seem to assume either that bees stay in the orchards in which they are placed, or else that all the orchards in the immediate neighbourhood will have colonies at an equal rate. If we assume that hives with an average field force of 15,000 bees are placed at the rate of one to the acre in a ten-acre orchard of large bearing trees with contiguous orchards surrounding it, aggregating 125 acres and that, under these conditions, the bees spread out only in a quarter-mile radius from the colonies and also assuming for the purpose of illustration that all trees are in bloom at once there should be present one bee for each 833 blossoms. If, however, we assume that the total field force from the ten colonies was evenly distributed ove the ten acres, the figure would be one bee for each 66 blossoms. It is, of course realized that all blossoms are not out at once, that the distribution is not ever and that the bees may fly considerably farther than one quarter of a mile but the illustration will serve to stress the point that the bee populatio of the surrounding area is an important factor in the utilization of bees i orchards. The situation is quite different, in cases where contiguous orchard are similarly supplied, from that created by the entire absence of bees in th surrounding area. This fact was repeatedly observed during the course of ou studies.

The writer, on one occasion in 1930, counted for two entire days in a te acre orchard in which ten strong colonies were placed, without observing single bee working the bloom, conditions for flight and bee activity being exce lent. Within a one-quarter mile radius there was a total of about 90 acres

orchard spread over approximately 200 acres of land. The point selected was 225 yards from the colonies. Six counters, placed in the orchard at intervals of from 3 to 225 yards from the hives, secured only an average of 0·37 bees per 10-minute count during the same period. In 1931, forty strong colonies were placed in the same orchard equally divided between the two ends of the orchard, the average counts giving a total of 0·62 per 10-minute count under very similar conditions. It was thus necessary to use four times as many colonies to get less than double the population in the bloom. Similar, or even more pronounced results were obtained elsewhere when colonies were placed one to the acre. The entire area in which our work has been done is heavily covered with orchard and at most stations the number of bees determined by counts was negligible. At Blomidon, in a fourteen-acre orchard with one colony per acre, we obtained, in 1930, only an average of ·22 bees per count. In this case the bees were placed at the north end of the orchard, with a mountain at the back covered by forest, while south and east of the colonies, stretched a solid block of orchard surrounding the one in which the observations were made.

On the other hand, on Long island where we had approximately 90 acres geographically isolated from other orchards and situated on a total land area of 640 acres, and with colonies present at the same rate, we had an average of 1·23 bees per count in 1931. In 1932, with stronger colonies and not more than 60 per cent of the bloom, our average count was 3·05 bees. Thus, on Long island, with one colony per acre of orchard, there were many more bees available for pollination than at Lakeville with four colonies per acre, since in the latter location the contiguous orchard area was unprovided with bees. In 1932, immediately before nsing them on Long island, 50 strong colonies were placed in an orchard at Somerset where 92 acres of orchard, within a half-mile radius, were at their maximum bloom. Here, in the orchard immediately contiguous to the hive, we secured an average count of 5·53 bees. This average is based on a 2-day count of optimum flight, whereas the Long island count is based on the period of bloom. The foregoing clearly indicates that, in making recommendations for placing hive bees in an orchard, it is necessary to consider not only the acreage of the particular orchard in which the bees are placed, but also the area of surrounding orchards and whether or not they are provided with bees. In other words, the district and not the orchard must be considered the unit for calculating the force necessary.

Our observations indicate that there must be a certain minimum population present under such conditions before a sufficient concentration of bees, in the particular orchard in which they are placed, can be assured. This minimum on the basis of our observation is about fifty colonies in an area solidly planted to fruit trees. In other words, if ten colonies are used to pollinate an orchard of ten acres, surrounded by 90 acres without bees, this would not necessarily ensure the pollination of that particular orchard which would require in the neighborhood of fifty colonies in order to ensure results.

With a population sufficient to give an average of one bee per 10-minute count, it has been estimated that each bee would be required to pollinate 250 blossoms in order that every blossom in the orchard, in a year of maximum bloom, should be visited. Coming again to Long island where conditions were more under control, we find that the counts taken over the whole island in 1931, a year of maximum bloom, amounted to 1·27 per count during several days of bloom and in 1932, with approximately 60 per cent of the previous year's bloom, 3·05 per count. Placing the lowest possible estimate on the number of blossoms that a colony of bees is capable of visiting, it would appear that one colony per acre, under conditions of isolation, would represent a population much greater than the number theoretically necessary. If our record of 3·05 bees per count, representing the force liberated by a strong colony with a field force of 15,000 bees or upward, is representative, even supposing that only 25 to 50

per cent were effective pollinators, it is obvious that each bee would have to visit only a comparatively small number of blossoms in order to pollinate the whole orchard. In considering this problem, allowance must be made for duplicate visits, proportion of nectar gatherers to pollen gatherers, etc. Though, in order to ensure pollination under unfavourable conditions, it is necessary to supply a much larger force than is theoretically necessary, it would appear that one hive to the acre of bearing trees should be quite adequate, even after all allowances are made.

In recommending a certain force per acre it should be emphasized that such recommendations only apply, in the case of areas heavily planted to orchard, where neighbouring orchards are similarly supplied. Colonies, set out at this rate in small blocks of orchard surrounded by hundreds of acres destitute of bees, spread out so thinly as to make them of doubtful value for pollination purposes. This point is particularly emphasized, because many growers in districts where no hive bees at all are present, consider it sufficient to use only a very few colonies, sometimes no more than one or two in a large orchard.

(x) *Method of Placing.*—Most studies that have been made with respect to the method of placing colonies in or about orchards, have had to do mainly with the problem of the best method of placement to follow in order to secure uniform distribution. There appears to be a wide difference of opinion between different workers as to the proper method of distributing the colonies.

Data secured by Hutson (1926) were said to indicate that the bees worked most freely near the hives and that by placing hives singly 210 feet apart each way and 15 feet from pollinizing bouquets, maximum results were secured and there was a uniform distribution of bees in the orchard. Counts show concentration about hives placed in groups, and the numbers diminish as distance from the hive group increases. Haseman (1932) states that colonies should be scattered through the orchard since, in cool weather, bees will not fly far. Marshall, Johnson, *et al.* (1929) emphasize the point that colonies should be placed near effective pollinizers. Murneek (1930) recommends that the hives should be distributed throughout the orchard and not kept in one sheltered corner. Within a heavily bearing orchard the greatest service will be secured when the colonies are placed 200 feet apart.

Philp and Vansell (1931) have a different idea as to the proper placing of colonies. They state that under ordinary conditions bees should be left in orchards in groups of 10 colonies. They point out that *sunshine, wind, temperature, rain,* and other factors outside the hive, affect the flight of bees and therefore general recommendations regarding placement are useless. If the weather is fair, bees can fly far enough to cover 100 acres of orchard, or more, from one location; but in cold weather flight is limited. They state that, under average conditions, bees in groups of 10 to 20 colonies, for as many acres surrounding them, have been found very satisfactory. Accessible situations should be chosen to facilitate placement and removal.

It was determined in our tests that, in a densely orcharded area supplied with colonies in groups, but at the rate of one per acre, little consistent difference occurred up to about 660 feet from the colonies; but after double this distance had been reached counts became definitely lower and beyond one quarter of a mile few bees were found. Since it is sometimes more convenient, both in placing and removing colonies, to distribute them in groups rather than singly throughout the orchard, it would appear to be satisfactory to have the colonies placed in groups one-quarter mile apart, having regard to the contour of the land and the other factors already discussed.

After experimenting for three seasons on methods of distributing colonies without being able to distinguish any great difference between colonies distributed singly and in groups, we arranged to carry out this latter plan on Long island

in 1932. The island being 2 miles long, the extreme colonies were placed approximately one-quarter of a mile from each end, and the remainder at approximately one-quarter mile intervals, there being 3 apiaries of 15 colonies and 3 apiaries of 16 colonies, or approximately one per acre of orchard. As there was a different number of counts on certain of the days, the data for June 2, June 3 and for the average count for June 4, 5, and 9 taken together, are presented. Counters were placed at the extreme ends of the island and midway between each of the apiaries, also at the two extreme apiaries and the centre apiary. While the error due to the human element in these counts may be large, it was apparent that the greatest number of bees was rarely present in the orchard adjacent to the apiary, and at all times the large number present at station " Y " was noticed by all observers. It would not appear, therefore, that the placing of colonies singly and evenly through the orchards could ensure an even distribution of bees, when the foregoing facts are considered. It would seem to be equally effective to place the colonies in groups at suitable intervals, with due regard to the position of orchards and the surrounding physical features, as good, or even better, distribution was obtained by placing groups of colonies at one-quarter mile intervals as by placing them singly in the orchard, though nothing like perfect distribution was ever obtained by either method. The habit of the bees of working nearer the hives during unfavourable conditions would render it inadvisable to place the colonies at greater intervals than that indicated. The accompanying table shows the results of counts made at the various stations on Long island.

TABLE 27.—AVERAGE COUNTS OF BEES FROM DIFFERENT STATIONS ON LONG ISLAND, 1932

Station	Average for June 2			Average for June 3			Average for June 4, 5 and 9		
	Hive bees	Wild bees	Number of observations	Hive bees	Wild bees	Number of observations	Hive bees	Wild bees	Number of observations
Z	....	....	....	9·09	1·34	41	0·59	0·85	85
1	....	....	....	4·78	3·06	41	0·88	0·78	85
A	1·46	0	13	13·85	7·27	41	0·76	1·93	85
B	2·62	0·31	13	9·35	2·39	41	0·61	0·29	85
C	5·54	0·08	13	6·54	2·85	13	0·22	0·30	27
C (emasculated blossoms)	....	....	....	0	0·29	7	0·08	0·08	12
C (depetalized blossoms)	....	....	....	0·33	0·5	6	0	0	12
4	....	....	....	7·25	5·71	41	0·45	2·64	85
D	16·75	0·15	13	10·90	2·56	41	0·59	0·66	85
E	4·61	0	13	8·28	1·27	41	0·26	0·18	85
6	....	....	....	5·93	1·61	41	0·82	0·62	85
Y	*	*	*	*	*	*	2·76	0·92	85

*No regular count on these dates but observations indicated bees to be abundant.

Where the apiary is situated near the orchard and permanent in position, it should be located with reference to the contour of the land so that the maximum number of bees will work in the orchard and not fly out of it. Steep banks in the neighbourhood of the orchard, or intervening belts of trees may, deflect the usual line of flight as already explained. With the apiary in a permanent location near the orchard the distribution of colonies throughout the orchard occasions loss. At the Experimental Station, Kentville, it was found that the colonies were much weakened by bees returning to the original stand, though a few weak colonies left behind to catch " drifters " was of benefit. When the colonies were returned to the original stand, bees that had emerged during the interval spent in the orchard, returned to the spot where their hive had rested, clustering on the spot for days, stinging all who approached. On the other hand, no such trouble was experienced from two apiaries each distant about a mile from the original stand.

(*d*) TIME OF PLACING

As regards time of placing, most workers state that best results can be expected when the bees are placed in the orchard only when the trees come into bloom and removed when the majority of the petals have fallen. There is an

added reason for doing this when danger of poisoning is to be anticipated. Our experience has been that this danger is materially lessened, though not necessarily eliminated, if the practice outlined above is followed, and it appears to be a sound one from every point of view.

(e) SOURCE OF POLLEN SUPPLY

Bees are useless in the orchard without a suitable pollen supply, a fact which appears to be often overlooked by growers. In fact it is quite conceivable that some harm may result. Bees placed in a block of self-unfruitful varieties may only result in rapidly selfing that variety, thus inhibiting a certain amount of crossing that might occur through the agency of wild species of bees before the period of stigma receptivity has passed. On the other hand, if cross-unfruitful sorts are mixed together, the pollination of the varieties concerned with the pollen of the other, may result in even less fruit than when certain varieties are selfed. Therefore, the proper provision and distribution of effective pollinizing varieties of apples is equally important to that of the insect pollinators and is something that is under the control of the owner who sets out the orchard.

The problems connected with the foregoing, however, have been discussed in detail elsewhere. In our work we have found the question of providing a suitable pollen supply of more practical importance than the provision of bees alone, and even using " bouquets " of fruitful varieties in connection with bees has usually been disappointing.

3. SECURING COLONIES

Three methods of using bees are suggested by DeOng (1925), as follows:—

1. Rental from a professional beekeeper.
2. Employment of a trained beekeeper to care for bees owned or leased by one or a group of orchardists.
3. Ownership and personal care.

The two first methods are considered best, as the orchardist usually has neither time nor knowledge to care for the bees properly. The difficulties of the average fruit grower are increased, under Nova Scotia conditions, on account of the evidence of poisoning, which may cause the beekeeper, and particularly the inexperienced beekeeper, to lose all his colonies, or to have them become so weakened as to be worthless for pollination purposes.

At the present time there is no one in the business of renting colonies to beekeepers in this province and there are not available a sufficient number of colonies to supply any real demand. Packages can be obtained from the South at the rate of from $1.75 to $2.75 for 2-pound packages, depending upon the source and number purchased at one time. Similarly, 3-pound packages will cost from $2.25 to $3.50; 4-pound packages from $2.75 to $4.25, and 5-pound packages from $3.50 to $5 each. Then, transportation charges will have to be added to the foregoing prices, and with proper care and attention, these packages can, if purchased sufficiently early, be put in condition to be of some service during bloom. The price asked by commercial beekeepers for strong overwintered colonies varies considerably in different fruit growing districts. As already stated, renting bees has never been practised in Nova Scotia, except in a few isolated areas, and accordingly few figures are available, but the risk of poisoning would probably force a maximum price.

Farrar (1929) states that in Massachusetts, beekeepers feel that they shoul[illegible] receive from $5 to $10 per colony. This writer suggests $5 as a fair price fo[illegible] a colony covering 5-6 frames, deducting $1.50 for each frame less, and adding $[illegible] for each frame in excess of 5 or 6 combs. Marshall, *et al.* (1929), in Michigan states that $2.50 to $3 per colony is the regular price in that state. Phillips (1930 [illegible] that labour and other inconveniences bring the cost to the beekeeper to a [illegible] cannot do the work or tak[illegible]

the necessary risk. He states that as high as **$10** per colony has been charged for rent. Philp and Vansell (**1932**), in California, emphasize the fact that the rental charged will depend upon distance of moving, state of roads, rainfall, supply and demand, etc., but that at the present time, **$2** will represent about the average price. Another possible method that has been suggested is for a group of orchardists to co-operate in securing colonies and engaging a beekeeper to tend them.

4. GENERAL CONCLUSIONS

While various causes prevented the complete carrying out of our studies as originally planned, the following conclusions seem justified on the basis of our investigations:

(*a*) It is generally recognized that the provision of hive bees to ensure pollination in apple orchards is a sound practice; but the experimental evidence in its favour is not so clear-cut as in the case of certain other fruits. In certain seasons, in some localities at least, adequate pollination is effected by native solitary bees.

(*b*) Where this condition does not obtain the provision of a suitable number of colonies should be practised as a part of the regular orchard routine and, even in cases where solitary bees may be adequate for pollination in favourable years, the placing of colonies in the orchard may be regarded as a wise insurance against seasons when conditions are unfavourable.

(*c*) Experimental evidence regarding the value of bees for pollination purposes under controlled conditions demonstrates clearly the necessity of bees combined with a supply of suitable pollen for all varieties. Even the most self-fruitful varieties require bees in order to ensure adequate pollination.

(*d*) Many factors, including colony strength and number of colonies in relation to the adjacent orchard area, the physical features of the area concerned, weather conditions and many others that have been discussed in detail in the foregoing pages, influence the flight, concentration and distribution of bees.

(*e*) The point is particularly emphasized that, in estimating the number of colonies per acre of orchard, the surrounding district and not the individual orchard should be considered the unit. The placing of a few colonies in an orchard area devoid of bees does not necessarily ensure the pollination of the particular orchard in which they are placed, since they may work mainly in another orchard or spread out too thinly over surrounding orchards to be of great value. The recommendation of one to the acre or one to four acres has little meaning, unless it is known that the surrounding area is similarly provided. Under conditions of isolation, or where neighbouring orchards are also provided with bees, one colony to an acre of mature trees should make adequate provision for pollination, even allowing for considerable unfavourable weather.

(*f*) Bees should be placed throughout the orchard area in such a way as to ensure as good distribution as possible and thus take advantage of short flights that may occur at intervals between periods of bad weather. Placing colonies at the rate per acre indicated, but in equidistant groups of from 5 to 15, depending upon the area in orchard, is regarded as satisfactory. Further details are given in previous pages.

(*g*) It is best to place the bees in the orchards when the earliest varieties are in full bloom and remove them before the petals have fallen from the later varieties.

(*h*) The proper distribution of cross-fruitful varieties in an orchard is a primary requisite to successfull pollination; without such provision, placing bees in the orchard only results in unfruitful selfing or crossing.

(*i*) Colonies may be rented from a beekeeper or they may be owned and cared for by the orchardist; but unless the latter is skilled in the care of bees, the former method is usually preferable. Another method suggested is for a group of orchardists to co-operate and hire a skilled beekeeper.

V. STUDIES IN BEE POISONING AS A PHASE OF THE ORCHARD POLLINATION STUDIES

By F. A. Herman and W. H. Brittain

A. INTRODUCTION

Owing to the importance of the evidence of poisoning among bees, in any consideration of their use for pollination purposes, the following studies were undertaken as an integral part of a pollination project undertaken by the Dominion Department of Agriculture in the Annapolis valley, N.S., during the years 1928-1932 inclusive.

In carrying out this work the writers have had invaluable assistance from Mr. C. B. Gooderham, Dominion Apiarist, in the way of active assistance and advice. A number of the photographs used in this report were also furnished by him. Mr. Evan Craig, Apiarist at the Experimental Station, Kentville, has given freely of his time, not only in caring for the bees used in the work, but also in helping with the actual work of the investigation. Mr. H. G. Payne, Provincial Apiarist, Truro, took an active part in the field studies and was of great assistance through his local knowledge of the industry.

B. HISTORICAL

Ever since the dawn of modern spraying practices, complaints of losses o bees from arsenical poisoning have been heard with increasing frequency, an laws prohibiting the applications of sprays during bloom have been passed b several states and provinces.

A number of chemists and entomologists have given the matter attentio and, while a complete review of the literature would be out of the question i the space available, a few of the more important contributions may serve t give a picture of the present state of knowledge with respect to this problen A more complete review has been given by McIndoo and Demuth (1926).

Webster (1896) was one of the earliest workers to conduct definite expe ments in connection with this problem. Paris green, 4 ounces to 50 gallo of water, was sprayed on a Lombard plum tree in full bloom at 2 p.m., t quantity of the mixture applied being just sufficient to wet thoroughly witho dripping. The tree was enclosed in canvas and mosquito netting; 5½ ho after spraying a hive of bees which had been placed near the tree some t weeks previously, was moved into the tent and the bees liberated. The follo ing morning many dead and dying bees were found on the tent floor. The de bees were examined by the Marsh method for arsenic, and yielded posit results. Further tests from washed bees were also positive. Several days la many more dead bees were picked up, and after washing, first with water, t with a weak solution of ammonia, were analysed and showed the presence arsenic. A small apple orchard, from which the bloom had all fallen excep belated cluster, was sprayed with Bordeaux mixture, to which had been ad Paris green at the rate of 4 ounces to each 50 gallons. A few days after application, three previously strong colonies of bees located nearby sudd became depopulated. Analysis of dead bees and dead brood showed the pres of arsenic. Conclusions drawn from these experiments are as follows:] are liable to be poisoned by spraying the bloom of fruit trees, the liab

increasing in proportion as the weather is favourable for the activity of the bees, and all the bloom must have fallen from the trees before the danger will have ceased.

Price (1920) conducted laboratory and field work to find out the amount of soluble arsenic necessary to kill a bee, to find out if a bee working upon a mixture of insoluble arsenic and syrup would take up the arsenic particles, and, if the dead bees contained arsenic internally. A small amount of arsenic of *less than ·0000005 grams of* As_2O_5 *is a fatal dose for a bee and the longevity* of bees poisoned with arsenic was found to depend upon the size of the dose. It was also found that a bee takes up lead arsenate particles in feeding on a sugar solution having them in suspension. An examination of dead bees from laboratory or field experiments showed arsenic to be present both internally and externally. It was found that bees worked freely on sprayed trees in the open, even when there were unsprayed trees all about and that trees sprayed while in blossom contained sufficient poison to cause a tremendous death rate. The mortality of bees in the control cage was 19 per cent, as compared with 69 per cent in the cages containing the trees sprayed with lime sulphur and lead arsenate, and 48 per cent in the cage containing the tree dusted with sulphur and lead arsenate.

Doane (1923) described a number of experiments conducted at Stanford University. An apple tree almost in full bloom was sprayed with arsenate of lead, 3 pounds of the poison to 50 gallons of water, and applied at the rate of 8 gallons of the spray per tree at a pressure of from 150 to 200 pounds; special effort was made to fill the calyx cups as far as possible. The tree was then tented and two days later a moderately strong colony of bees was placed beside the tree. Before liberating the bees on the following morning, 2 gallons more of the spray were applied to the tree in the form of a fine mist so as to cover the leaves and petals. Shortly after being liberated, some of the bees visited the blossoms and by noon scores of them were feeding freely. Three days later the colony was returned to the apiary and, on examination, the bees were found to be working normally, that honey had been stored while working the sprayed bloom, that the larvæ were in a normal condition and that the queen had been laying eggs. During the three days the bees had been feeding on the poisoned bloom only a few had died which on examination showed ·00000255 grams of arsenic per bee. The bees that were collected while still living showed ·000002 grams of arsenic per bee. Bees from the check tent contained ·0000006 grams of arsenic per bee.

These experiments were repeated several times with other colonies and no abnormal effects noted. In a later experiment a tree just coming into bloom and in which bees were feeding was sprayed with dry acid lead arsenate, 4 pounds per 50 gallons. While most of the bees were driven away by the spray, they returned within ten minutes after spraying was stopped. The weather was warm, favourable for the activity of the bees. No poisoning was observed. An examination of the hive showed that the bees and brood were in good condition and that the bees had stored honey during the time they fed on the treated bloom.

The conclusion arrived at is that there is no danger of poisoning bees by spraying fruit trees when they are in bloom, a procedure that is common in certain parts of California.

Merrill (1924) criticises the methods employed by Doane and concludes that the work of Price is more scientific and the results more likely to be correct.

Tietz (1924) has studied the question of the solubility of arsenate of lead in the digestive fluids of the honey bee. He points out, that in order that a poison may be absorbed by the body and so cause death, it is necessary that

it should be in a soluble form. When arsenate of lead is taken into the alimentary tract of an insect, it is very insoluble. The average arsenate of lead powder contains about 32 per cent arsenic pentoxide, and as the insect consumes but a small quantity of the spray, the solubility must increase when the powder comes in contact with the digestive fluids in the alimentary tract; otherwise the quantity of arsenic capable of assimilation would be so small that the insect would be unharmed by its presence in the blood.

The solubility of arsenate of lead powder in water was taken as the unit of solubility. The following conclusions were drawn from the experiment: (1) The solubility of arsenate of lead does not seem to increase when the powder is acted upon by the fluids in the oesophagus. (2) The digestive secretions of the honey stomach and stomach render the poison at least one and one-quarter times as soluble. (3) The action of the intestinal juices is to throw at least three and three-quarter times as much of the powder in solution as would be dissolved by water alone.

McIndoo and Demuth (1926) have conducted careful and extensive experiments upon the effects on honey bees of spraying fruit trees with arsenicals. They also give an excellent review of work carried out up to the data of publication. Experiments at Winchester, Va., in 1914, in which 3 small isolated orchards in bloom were sprayed with (*a*) Paris green, (*b*) lead arsenate and (*c*) lead arsenate and lime sulphur, brought out the following points: (1) Bees work as well on sprayed as on unsprayed bloom; (2) they do not fly away very much from the sprayed orchard if it is well isolated; (3) they are slightly affected when a small orchard is sprayed in full bloom; and (4) the arsenate of lead-lime sulphur mixture was found best for experimental purposes. Larger experiments conducted the same season in a large isolated commercial orchard at Winthrop, Me., using the latter mixture, caused serious losses to the bees, pollen proving to be the main source of poisoning. While never more than traces were found in the partially ripened honey, chemical analysis of the nectaries revealed traces of arsenic. None of the ten colonies used was killed outright, but five were depopulated in a very short time and five were weakened. The foregoing results were obtained by daily observations, the use of dead-bee traps and analyses of samples. In later experiments a method was followed whereby the actual weight of the bees could be determined daily. Experiments conducted when the trees were sprayed at the ordinary time, *i.e.*, when 90 per cent of the blossoms had fallen, gave little or no poisoning. Laboratory experiments established that a fatal dose of arsenic (As) per bee is about 0·0004 or 0·0005 milligrams.

Hilgendorff and Borchert (1926) describe observations in which the application of arsenical compounds, by aeroplane, to forests for the control of the "fir noctuid" moth and "nun" moth caused a serious bee mortality to the Sorauer beekeepers and claims for damages were instituted. Chemical analysis of the bees showed living bees to contain ·00015 mg. of arsenic; washed dead bees, ·00025 to ·004 mg.; pollen, ·0001 to ·0005 per cent, while bees, pollen and honey from districts not subjected to arsenical preparations contained no arsenic. The quantities of arsenic in the pollen were quite sufficient to cause bee mortality, as shown later by feeding experiments with sugar solutions containing arsenic in proportion to that found in the pollen.

Bourne (1927) presents considerable experimental evidence with respect to the poisoning of honey bees by orchard sprays. Experiments were conducted to ascertain whether bees were attracted or repelled by common spray mixtures, and whether the latter had any injurious effect on the bees. First, a single frame nucleus in an observation hive was fed for a few days on dilute honey, then on a mixture of honey, one part, and spray mixture (lead arsenate, lime sulphur and nicotine sulphate), one part. They readily accepted the honey, but were repelled by the mixture. Only a few fed on it and these, after being isolated,

died in 24 hours. When only lead arsenate was used they showed no reluctance in feeding. The colony was exterminated after feeding on the last mixture for nine days. A combination of lead arsenate, lime sulphur and honey was also accepted readily; in fact, the nicotine sulphate seemed to be the only repellent, as all combinations not containing it were eaten freely. All three substances proved toxic, lead arsenate the most so, and the combination of all three was most deadly. A three-frame nucleus with eggs, brood and some stores was then placed in a greenhouse, and supplied with bloom sprayed with the regular spray combination. The bees were repelled by the sprayed bloom, but still worked it in considerable numbers. The mortality rose to about 399 per day within three days after exposure to sprayed blossoms, whereas it had been from 7 to 63 per day, before. A normal ten-frame colony was then placed in an orchard which was sprayed with a combination of lead arsenate, 1½ lbs. to 50 gallons, lime sulphur, 1-40, and nicotine sulphate 1-1000 when the centre blossoms had just opened. Bees which actually worked the bloom were poisoned, but owing to the repellent action of the spray and the rapid opening of unsprayed blossoms, damage to the hive was negligible. An early calyx spray gave the same result.

Another colony was placed in a tent, which was erected over a 12-year-old peach tree. After being left for a few days and when considerable bloom had opened, the tree was sprayed with the combined spray; another application was made at full bloom. No high mortality was noted except following a spray of lead arsenate alone. Unfavourable weather conditions which prevented the bees from working may have been partly responsible.

Under conditions in Massachusetts, the orchard sprays applied nearest the period of bloom are the "pink" and the "calyx." No sprays are scheduled to be made when trees are in full bloom. Neither of these sprays, made when there was considerable bloom on the trees, caused any serious mortality of colonies located in the sprayed orchards. Following the "late pink" trees soon came into full bloom; after the "early calyx," the bees repelled by the spray doubtless foraged in neighbouring orchards. In both cases they found an abundance of unpoisoned bloom upon which to work. This would indicate that improper spraying must be carried out on a large scale visibly to affect colonies not subject to any restrictions of flight.

Borchert (1930) has investigated the action of copper compounds commonly used, both sprays and dusts, also copper sulphate and basic copper carbonate, on bees. The poisonous effect was found to be less, the more firmly the substance clung to the bee's body. Poisoning was through the mouth in all cases; evidently the bees swallow the substances in cleaning themselves, and are not so likely to be poisoned if they cannot easily remove them. The lethal dose for a bee was found to be equivalent to about 0·009 mg. of metallic copper. (Thus, dust or spray substance containing one pound of metallic copper would suffice to poison about 53,000,000 bees.)

Philp and Vansell (1932) state that spraying fruit trees results in contaminated nectar and pollen, as well as cover crops. Bees also drink poisoned dew from leaves, so that even careful spraying cannot entirely eliminate poisoning, particularly where cover crops exist.

C. DEVELOPMENT OF PROBLEM

Previous to 1916, we have little evidence regarding the condition of the bee industry. In that year a total of 70 apiarists were visited in the territory to which our studies have been largely confined, *i.e.*, the area bounded by Grand Pré on the east and Berwick on the west. No further survey was made until 1919 when only 58 were visited, mostly those that had been visited before. Thus, we have no records previous to 1916, and only incomplete records for the years 1916 and 1919. We cannot now determine, therefore, all the apiaries

that were in existence at that time nor the subsequent history of all of these apiaries, but we now have accurate knowledge of the number at present existing and can trace the history of the great majority.

Of the total number of farms known to be supplied with bees in 1916-1919, fifty-nine had none in 1930. Of the remainder, one represents the Experimental Station apiary, which has only been kept in existence by the most assiduous care; at least two are known to practise migratory bee-keeping and eleven are in the towns of Wolfville and Kentville where poisoning, as would be expected, is at a minimum. One man who formerly had twenty colonies now has three. With these exceptions all others have disappeared. The apiaries that have been wiped out include some that were the largest in the Valley, one having once contained 100 colonies and one 40. The only apiarists who operate on anything approaching a commercial scale have been obliged to adopt migratory bee-keeping. The above would indicate a mortality much greater than would be expected from normal causes, especially as the matter of foul brood among the bees has been kept well in hand.

From time to time new apiaries have sprung up, and it will be interesting to note what happened to them. Excluding the towns, the Experimental Station and the migratory beekeepers, we find that 16 beekeepers are recorded for the first time in 1920. Fourteen of these apiaries were out of existence in 1930; one consisting of three colonies, was maintained at that strength; one of twenty-five was reduced to eight and some packages had been obtained by purchase. Figures for other years might be given, but they tell the same story.

There is, no doubt, a large mortality among bees, due to various factors of which the most important is lack of efficient handling. The history of bee-keeping in the Valley, however, shows large losses among the most experienced apiarists; and apiaries that had been maintained successfully for many years previous to 1919, were suddenly and completely wiped out. In the great majority of cases the evidence points unmistakably to poisoning. The only beekeepers retaining apiaries of commercial size have practised the removal of their colonies throughout the danger period.

It would not appear to be a coincidence that this extermination of colonies took place during and following the year 1919, since this was the year in which the Valley fruit-growers suddenly adopted dusting, a large proportion of the orchards in the Valley being dusted for the first time in that year and for several years following. The figures of growers' purchases of such materials for a few typical years reveal this very sudden change in practice. They also reveal the increased quantity now being used to cover the same acreage.

It should not be assumed, however, that no trouble from poisoning existed before that period. While it is true that we have few definite records on this point, it is also true that many beekeepers regarded poisoning from sprays applied in bloom as one of their greatest sources of trouble. Nevertheless, many of them who were quickly wiped out following the widespread adoption of the dusting method, had been able to maintain successful apiaries for many years in spite of occasional poisoning.

The increased amount of poisoning from the dusting method has been generally attributed to three causes:—

1. The greater drift of the dust to surrounding vegetation, which thus contaminates other bloom such as dandelion, wild radish, etc., growing in or near the orchard.

2. The greater amount of arsenic applied per acre when following this method.

3. The difference in the character of the deposit. Spray quickly dries on and is difficult to remove. Dust makes a loose layer over leaves and blossoms, is gathered by or becomes attached to the hairs of the bee and is stored with the pollen.

With the development of more efficient spray machines and nozzles delivering a greater quantity of spray per minute and the recognition of the fact that dusting was giving inferior results against certain pests, there has come a decided swing back to the spraying method during the past four years. As far as can be determined there has been a sale of approximately 90 spraying outfits per year over this period as compared with approximately three dusters and the latter have been used largely to supplement spraying practices in the way of additional fungicide applications or for the application of nicotine dust. The new types of spraying nozzles, however, deliver quite a different type of spray from that of the old type, being more in the form of a fog, which drifts on to surrounding vegetation to a greater extent than could occur where old style nozzles were used. Furthermore, the greater number of gallons used and the increased strength employed by many growers are added factors. It is not surprising, therefore, that indications of greater poisoning of bees, due to spray applications have become apparent during the past few years.

The foregoing is only intended as a general outline of the situation, in order to serve as a background for the more definite observations and experiments carried out since 1928.

D. EXPERIMENTS IN BEE POISONING

1. FACTORS INVOLVED IN CARRYING OUT AND INTERPRETING RESULTS OF POISON STUDIES

There are a number of difficulties inherent in both tent and field experiments with bees that render it difficult properly to plan such experiments, and still more to interpret their results.

It is a comparatively easy matter to feed bees upon definitely measured doses of various materials in the laboratory, but to secure similar results under tents or in the open orchard is quite a different problem. Some of the most important difficulties are here set forth in order clearly to portray the limitations of such work.

(*a*) In experiments carried out under tents covering trees, certain unnatural conditions develop. Immediately bees are released, a large number fly to the top of the tent and remain there in spite of all attempts to dislodge them. There, a number may become chilled or die of starvation and keep dropping down on the floor of the tent, interfering with the counts of dead bees. This trouble is most apparent when periods of dull, cool weather prevail. Clustering at the top may be partially prevented by covering the tops with a dark sheet.

Since the bees are forced to feed upon the treated bloom, the results obtained are liable to be accentuated over those that would occur under field conditions. At any rate, they are not strictly comparable, though, if correctly interpreted in the light of all relevant factors, they may yield results of value. Another disturbing factor is that during periods of rainy weather, the bees will lap up the water that drips from the limbs or trunk and thus consume considerable quantities of the material supplied, dissolved or suspended in the water, which they might not do under out-of-door conditions. This results in materials not ordinarily considered violently poisonous, sometimes causing a high mortality. Residue from previous sprays, may, under such conditions, cause certain losses.

(*b*) In field experiments it is equally difficult to control the conditions of the test. Several workers speak of their experiments being conducted in "isolated" orchards. We have been quite unable to obtain isolated orchards for our work, since in every case, there are other orchards sufficiently near for bees to visit, and one could never be certain that the results noted were caused by materials applied in the orchard in which the bees were placed or obtained from a distance.

The habit of bees gathering supplies from a limited area has been clearly brought out in these experiments. An example might be cited of a case observed at the Experimental Station in 1929. Only one colony of the fifty showed distinct signs of poisoning and in this case the loss was heavy. The orchard was sprayed while there was a certain amount of bloom, mostly with lime sulphur-calcium arsenate. However, there were a few small plots devoted to spraying and dusting experiments, one of which had received 90-10 sulphur-lead arsenate dust. Evidently this colony obtained its supplies from a location different from the other bees and it may have foraged chiefly on this block. In several cases where numbers of hives were standing together certain individual colonies showed much worse poisoning than others, irrespective of colony strength or other factors.

(*c*) In both field and tent experiments the condition of the colony is important. It is impossible to secure colonies of identical strength and vigour. Some were noticeably "sluggish", worked the bloom less actively, and so received less poison. The results of varying weather conditions profoundly modify the results of both tent and field experiments. These are discussed at greater length in another section. It is sufficient to point out that very erroneous results are obtained if this factor is ignored.

2. POISON USED, SYMPTOMS AND LETHAL DOSAGES

(*a*) Of the spray materials used in Nova Scotia the following are the most important:—

(i) Food Poisons:
Calcium arsenate
Arsenate of lead

(ii) Contact Poisons:
Nicotine sulphate (liqnid)
Nicotine sulphate-lime (dust)

(iii) Fungicides:
Bordeaux mixture
Lime sulphur
Sulphur dust
Copper lime dust ("Bordeaux dust").

Various combinations of these may be used, the fungicides generally having the arsenical added, and frequently representatives of all these groups are mixed together. Experiments under tents and in the field with these and all combinations used commercially were carried out.

(*b*) SYMPTOMS AND EFFECTS OF POISONS

(i) *Arsenical Poisons.*—The results of arsenical poisoning in whatever form are most apparent. "Crawlers" soon appear in front of the hive, their limbs appearing to be partially paralyzed. Clumps of bees often cluster together in bunches. The abdomen becomes distended and when subjected to pressure readily bursts. A pronounced dysentery is often apparent, the hives becoming badly spotted. This effect is most pronounced when the arsenic is contained in a sulphur preparation. After a period of crawling, twisting and squirming, the poisoned bees gradually become immobile and only feebly respond to stimulation for some time before death ensues.

It was a notable fact that none of the "crawlers" taken in front of poisoned hives had pollen in their pollen baskets. They evidently entered the hive and came out to die after having gotten rid of their load.

(ii) *Nicotine.*—Certain cases of nicotine poisoning under field conditions are not available. As nicotine quickly volatilizes and, when applied as dust, is usually used at night or early morning when no bees are flying, heavy mortality from this source would not be expected. In tents, in which heavy dust applications were made, bees sometimes became completely covered with the nicotine lime dusts and some poisoning developed. In some years trees sprayed with this material also produced killing. Definite feeding experiments performed by other workers are available. It would appear that symptoms caused by this poison are not as violent as those produced by arsenical sprays. There is little motion, and, where the poisoning is insufficient to cause death, quick recovery results. Otherwise complete paralysis is followed by death.

(iii) *Sulphur.*—Sulphur applied in the form of sulphide sprays or elemental sulphur in the form of dust causes pronounced dysentery. In tent experiments a certain amount of mortality was caused, but under field conditions it was believed that most of the bees recovered. Severe spotting of clothing hung out to dry has resulted from the use of this material in several cases.

(iv) *Copper.*—Copper fungicides as yet have not been definitely proved to cause death to bees under field conditions and the evidence would appear to indicate that they are quite safe to use. Where fed to bees or when wet weather prevails they may cause death. The insects become sluggish, lose their power of movement and finally death ensues, only more slowly than with arsenical poisons.

Repellent Action of Sprays.—Lime sulphur was the only material found definitely repellent by McIndoo and Demuth (1926). Bourne (1927) found nicotine also to be repellent. Repulsion to these materials is hard to demonstrate under field conditions and, if it exists, it would appear to have little practical effect. In making our observations, we have repeatedly observed the action of different materials including poisoned Bordeaux, lime sulphur alone or in combinations with calcium arsenate, or with the latter and nicotine sulphate, 90-10 sulphur-lead arsenate and other combinations. We have also studied the effect of the commercial materials and combinations when applied to bouquets and, in all cases, could obtain little consistent evidence of prolonged repulsion under field conditions, the bees sometimes settling quickly upon the trees as fast as the machine passed. In few cases was the repulsion of long duration. In one case lime sulphur-calcium arsenate appeared to repel for 17 hours. In most cases the repulsion was of only a few minutes duration and was apparently over by the time the material had dried. Sulphur-lead arsenate actually seemed to attract. These observations are based on definite counts of wild and hive bees visiting bloom treated with different materials, unsprayed bloom being available in all cases.

(*c*) LETHAL DOSAGES

Data obtained from analyses of bees (package and hive) that had died from natural causes and those dying in check tents, where no poison had been applied, showed arsenic present, as metallic arsenic, from ·00004 to ·00008 milligrams of internal arsenic (As), and from ·00004 to ·00009 milligrams of total arsenic (As), internal plus external, per bee. No traces of arsenic were found in check samples of larvae, pollen or nectar, but minute quantities were found in pupae.

From this data we may assume that when the internal arsenic found in adult bees is greater than ·00004 milligrams of metallic arsenic per bee, poisoning may be suspected; definitely so, when higher than ·00008 milligrams of metallic arsenic per bee are detected. Analyses of adult bees, larvae, pollen,

pupae and nectar from locations where no poison of any kind was used an where no poisoning was obtained, are given for purposes of comparison wit subsequent observations in which poisoning actually occurred.

TABLE No. 28.—ANALYSES OF CHECK SAMPLES OF BEES, LARVAE, POLLEN, PUPAE AND NECTAR

Sample No.	Nature of material	From bees (Internal) Mg.	Wash water from bees (External) Mg.	Total internal plus external Mg.	Average arsenic (As) per bee (Internal) Mg.	Remarks
1	Bees........	·003030	·001273	·004303	·00003	100 bees used in each sampl except No. 1a, when 19 bee were taken.
1a	"	(bees not washed)	....	·001270	·00006	
2	"	·002500	·001000	·003500	·00003	
2a	"	(bees not washed)	....	·004550	·00005	
3	"	·004050	·000700	·004750	·00004	
3a	"	(bees not washed)	....	·004022	·00004	
4	Larvae......	....	....	....	nil.	
5	Pupae.......	....	....	....	·00007	·00008 %; 10 pupae used.
6	Pollen......	....	....	....	nil.	1·5390 gs. used.
7	"	....	....	....	nil.	0·9038 g. used.
8	Nectar......	....	....	....	nil.	Nectar pipetted from combs approximately 3 grams i each sample.
9	"	....	....	....	nil.	
10	"	....	....	....	nil.	

3. TENT EXPERIMENTS IN BEE POISONING

In 1928-1929 tents were placed over entire trees, which were spraye during bloom, and a hive of bees placed in the tent immediately thereafter In 1930 and 1931 large bouquets were used instead of entire trees. In view o the great amount of data secured and the limitations in accuracy from suc experiments, only the more outstanding results are included in the followin report.

Following the application, observations as to the reaction of the bees to th different materials and on the daily mortality were made. The dead bees wer counted every day from the floor of the tent upon which sheets were placed until mortality ceased. Following 1930, "dead-bee traps" of the type use by McIndoo (1926) were employed, but modified so as to have a removabl bottom board from which the top could be lifted and the dead bees readil removed. After pronounced poisoning had developed, we removed the bee from the tents, placed the traps in place and based further counts on dail removals of dead bees from the traps.

Chemical tests were made of dead bees and of brood available. Sufficien pollen or nectar was rarely available from bees tented over a single tree; bu pollen and nectar from bad cases of field poisoning are reported on elsewhere.

(a) TECHNIQUE OF CHEMICAL TESTS

When the dead bees were received at the laboratory two chemical pro cedures were followed. In one instance, the bees were analyzed as received— no attempt being made to remove external poison, the arsenic present in adherin dust or other forms on the body of the bee.

In the procedure generally followed, the bees, usually 100 in number, wer placed in a suitable bottle and washed, by gentle agitation, with 4-25 ml. aliquot

of 2 per cent nitric acid (by volume). After each washing the liquid or wash water was poured through a filter. The bees were then washed in the filter with 20-30 ml. of distilled water, and finally with 10 ml. of alcohol.

For destruction of organic matter, the samples of pollen, nectar, larvae, pupae, bees as received, wash water and washed bees with filter paper were treated with 10-15 ml. of conc. sulphuric acid and charred on the hot plate. Concentrated nitric acid was then added, the liquid heated, and more acid

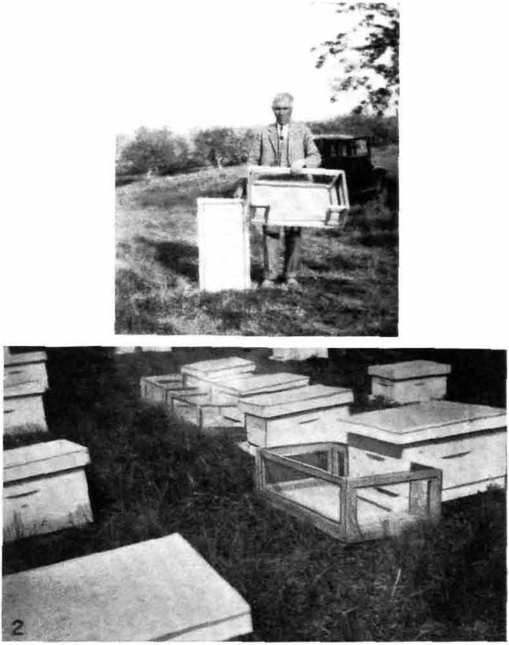


FIG. 69.—(1) Modified McIndoo trap, showing removable bottom board; (2) modified McIndoo trap in place (original from photo by C. B. Gooderham).

added until finally a colourless solution was obtained. This solution was evaporated to dryness, washed into a modified Gutzeit generating flask, and arsenic determined by the Gutzeit method.

The arsenic found on analysis of the washed bees is designated internal arsenic; that from analysis of the wash water, external arsenic—the sum of the two, total arsenic. The total arsenic is also obtained by analyzing the bees direct as received, *e.g.*, not washing with nitric acid previous to analysis.

(b) EXPERIMENTS IN 1928

The following materials and combinations were utilized in 1928 and the results of the tests from a standpoint of mortality and chemical analysis are found in the accompanying tables. Only those materials that gave a greater mortality than the checks are shown in the table. All others gave either the same results or a lesser mortality.

The following spray dust preparations were applied to the tented trees:—

SPRAYS

Tent No. 1—Bordeaux 3-10-40.
" No. 2—Nicotine sulphate (1 pt.-100 gals.)
" No. 3—Calcium arsenate (1-40).
" No. 4—Bordeaux (3-10-40)-Nicotine sulphate (1 pt.-100 gals.)
" No. 5—Bordeaux (3-10-40)-Calcium arsenate (1-40).
" No. 6—Bordeaux (3-10-40)-Nicotine sulphate (1 pt.-100 gals.)-Calcium arsenate (1-40)
" No. 7—Lime sulphur (1-40).
" No. 8—Lime sulphur (1-40)-Nicotine sulphate (1 pt.-100 gals.)
" No. 9—Lime sulphur (1-40)-Calcium arsenate (1-40)
" No. 10—Lime sulphur (1-40-Calcium arsenate (1-40)-Nicotine sulphate (1 pt.-100 gals.)

DUSTS

Tent No. 11—Sulphur (95-5).
" No. 12—Nicotine-(5% nicotine sulphate).
" No. 13—Sulphur-Lead arsenate (90-10).
" No. 14—Poisoned Bordeaux (12-8-80).
" No. 15—Copper carbonate-Lime-Nicotine sulphate (9-86-5).
" No. 16—Check.
" No. 17—Check.

(i) *Results from Standpoint of Mortality, 1928.*—The most outstanding point in connection with these results was that all the combinations containing nicotine showed lower mortality than the checks, except No. 10, which included calcium arsenate. All Bordeaux combinations gave less than the checks, except No. 5, which contained calcium arsenate. All mixtures containing lime sulphur, except No. 8, which contained nicotine sulphate, and sulphur dust gave a higher mortality than the checks, even plain lime sulphur showing some loss. Sulphur dust caused dysentery, but less mortality than where arsenicals were present. Sulphur-lead arsenate was particularly deadly and sudden in its action, a fact which checks up with field data and chemical tests. Only arsenical and arsenical combinations produced dead brood.

TABLE No. 29.—TABLE SHOWING TOTAL MORTALITY ON 2nd, 3rd, 4th AND FINAL DAY OF COUNT

No.		Material	Total number Dead on Different Days			
			2nd.	3rd.	4th.	Final Total
1	13	Sulphur-lead arsenate dust	200	1,900	1,900	4,083
2	10	Lime sulphur-Calcium arsenate-Nicotine sulphate	0	380	663	3,368
3	3	Calcium arsenate	0	698	1,512	3,284
4	9	*Lime sulphur-Calcium arsenate*	0	405	819	2,069
5	5	Bordeaux-Calcium arsenate	0	304	516	1,981
6	11	Sulphur dust	242	342	384	1,773
7	7	Lime sulphur	0	349	504	1,483
8	17	Check	52	42	—	1,230

(ii) *Chemical Data, 1928.*—Taking ·00004 to ·00008 milligrams of metallic arsenic as the lethal dose per bee, we find a condition of bee poisoning to exist on May 31 and June 1, the first days' mortality, as follows:—

Tent No. 3—Calcium arsenate-·00086 milligrams per bee.
" No. 5—Bordeaux-Calcium arsenate-·00099 milligrams per bee.
" No. 6—Bordeaux-Calcium arsenate-Nicotine sulphate-·00046 milligrams per bee.
" No. 9—Lime sulphur-Calcium arsenate-.00036 milligrams per bee.
" No. 10—Lime sulphur-Calcium arsenate-Nicotine sulphate-·00045 milligrams per bee.
" No. 13—Sulphur-Lead arsenate-·00106 milligrams per bee.
" No. 14—Bordeaux (12-8-80)-·00042 milligrams per bee.

It will be seen that in all cases the minimum lethal dose is greatly exceeded in these samples. While the bees collected from the check tents in this experiment showed, from ·00014 to ·00017 milligrams of metallic arsenic per bee, this high figure is due to poison residue obtained from previous sprays and apparently imbibed in drip water consumed by bees following rains. Later work has shown that from ·00004 to ·00008 milligrams of metallic arsenic represents more closely the quantity of arsenic per bee that dies from natural causes. Subsequent analyses of adult bees, together with larvæ and pollen from certain of the tests showing heaviest mortality, were made, and the data presented in the following table. Owing to the comparatively small amount of forage afforded by a single tree, it was only possible to secure larvæ and pollen samples from a few tents and no nectar samples were procurable.

TABLE No. 30.—ARSENIC, AS METALLIC As, FROM CHEMICAL ANALYSES OF BEES UNDER CAGE CONDITIONS, 1928

Tent number and date of collection	Number of bees analysed	Arsenic (As) in milligrams			
		From bees (a)	Wash water from bees (b)	Total bees plus wash water (c)	Average quantity of arsenic (As) per bee (d)
17 Check May 31	40	·00682	·00341	·01023	·00017
16 " June 1	100	·01439	(e)	·01439	·00014
3 " May 31	100	·08633	·01212	·09845	·00086
3 " May 31	100	·11510	(e)	·11510	
3 " June 1	100	·04392	·05755	·10147	·00044
3 " June 4	100	·10602	(f)	....	·00106
3 " June 7	100	·12722	(f)	....	·00127
5 " May 31	100	·09996	·04847	·14843	·00099
5 " June 4	100	·04241	(f)	....	·00042
6 " June 4	100	·10299	(f)	....	·00103
6 " June 6	100	·04544	(f)	....	·00045
9 " May 31	100	·03636	·04241	·07877	·00036
9 " June 1	100	·10602	(e)	·10602	
9 " June 4	100	·04241	(f)	....	·00042
10 " June 1	*100*	*·04544*	*·09694*	*·14238*	*·00045*
13 " May 30	100	·21507	·06816	·28323	·00215
13 " May 31	100	·10602	·08028	·18630	·00106
13 " May 31	50	·17268	·03938	·21206	·00345
13 " June 4	100	·04847	·05756	·10603	·00048
13 " June 4	100	·15752	(e)	·15752	....
13 " June 6	100	·08197	(f)	....	·00082

(a) Total quantity of arsenic (As) within the body of the bee.
(b) Arsenic (As) carried outside the body of the bee.
(c) Includes arsenic (As) within and without the body of the bee.
(d) Average quantity of arsenic (As) per bee within the body.
(e) Bees not washed previous to examination. (Internal and external (As)).
(f) Washed bees only examined. (Arsenic (As) within the body of the bee).

TABLE No. 31.—ARSENIC, AS METALLIC As, FROM LARVAE, 1928

Source of Poisoning	Number	Weight	Arsenic (As)	
			Per larva	
		gm.	p.c.	mg.
No. 3 Calcium arsenate—June 8	4	0·131	·00173	·000568
No. 9 Lime sulphur-calcium arsenate—June 6	15	0·707	·00114	·000529
No. 13 Sulphur-lead arsenate—June 5	30	2·633	·00150	·001313

(c) EXPERIMENTS IN 1929

Tent studies were continued in 1929 along similar lines to those of the preceding year. It was found impossible to start all the experiments at once; consequently it was necessary to initiate a series on two distinct dates. Weather conditions are believed to have played a greater part in some cases in the results secured than the actual differences between materials. Analyses of bees from all tbe tents were made, as in 1928. In order to avoid repetition and conserve space, however, the principal points brought out in the two years' tests are shown in the accompanying table, and analyses of pupæ from certain of the poisoned colonies, in the table which follows it. Analyses of pollen collected during this season are shown elsewhere.

TABLE No. 32.—SUMMARY OF RESULTS WITH ADULT BEES

No.	Material	Order of mortality[1]		Average arsenic per bee, milligrams	
		1928	1929	1928	1929
1	B.	X	X	X	X
2	N.S.	X	X	X	X
3	C.A.	3	4	·00044–·00127	·00003–·00050
4	B. + N.S.	X	X	X	X
5	B. + C.A.	5	2	·00042–·00099	·00004–·00023
6	B. + C.A. + N.S.	X	X	·00042–·00103	·00008–·00018
7	L.S.	7	3	X	X
8	L.S. + N.S.	X	X	X	X
9	L.S. + C.A.	4	7	·00036–·00042	·00003–·00018
10	L.S. + C.A. + N.S.	2	6	·00045	·00006–·00018
11	S. Dust	6	5	X	X
12	N.S. Dust (2%)	X	X	X	X
13	S. + L.A. Dust	1	1	·00048–·00215	·00011–·00055
14	B. + C.A. Dust	X	X	X	X
15	CuC. + N.S. Dust	X	X	X	X
16	Check	X	X	X	·00004–·00008

B. = Bordeaux; N.S. = Nicotine sulphate;
C.A. = Calcium arsenate; L.S. = Lime sulphur;
L.A. = Lead arsenate; CuC. = Copper carbonate;
S. = Sulphur.

[1]The material showing highest mortality rate is numbered.
X. Less mortality than checks.

TABLE No. 33.—ARSENIC AS METALLIC As, FROM PUPAE, 1929

Source of Poisoning	Number	Weight	Arsenic (As)	
				Milligrams
		gms.	p.c.	per pupa
No. 3 Calcium arsenate.....June 11	3	·0932	·00244	·00076
No. 16 Check.....June 11	13	·9060	·00025	·00018

(d) SUMMARY AND CONCLUSIONS FROM TENT STUDIES OF BEE POISONING, 1928-1929

The inconsistent mortality from the different spray materials in the different years indicates that we cannot draw definite deductions from one season's operations, since difference between colonies, effects of weather conditions and other factors lead to highly irregular results. With the dust preparations, Bordeaux dust causes some mortality, sulphur dust heavy mortality where the bees are confined, probably due to the severe dysentery produced, but the highest mortal-

ity is caused by the use of sulphur-lead arsenate dust. The high mortality from this combination whether 90-10 or 85-15 has been unquestionably demonstrated year after year.

Owing to the situation outlined, conclusions on all points can be attempted only with caution; but, making allowance for all irregularities and inconsistencies, and bearing in mind the field evidence available, the following general conclusions appear justifiable:

1. Sprays containing arsenicals are dangerous to bees when applied during bloom.
2. Only sprays or dusts containing arsenicals caused dead brood in these tests.
3. The combination causing the most sudden and the heaviest mortality was sulphur-lead arsenate in dust form.
4. Generally, but not invariably, less toxicity appears to be exhibited by sprays or dusts containing nicotine or copper sulphate as an ingredient.
5. Unpoisoned sulphur dust, in addition to causing a pronounced dysentery, may also cause the death of bees. Just how important this may be under orchard conditions is not clear, but apparently it is much less dangerous and slower in action than arsenicals.

(e) REPULSION TESTS 1930-1931

Tent studies were continued in 1930-1931 mainly with the object of securing information regarding the repellent action of different spray and dust materials. Tests were run in duplicate, and both treated and untreated bloom were available to the bees; tubs filled with limbs of bloom in good condition being used.

Counts were made at intervals on the different treated bouquets to determine the number of hive and wild bees visiting each, as compared with those visiting the untreated bouquet in the same tent. As in the poison tests, the evidence was to some extent conflicting in the different years; and furthermore, different colonies reacted differently to the ingredients used. Weather conditions again had an important influence.

Careful study of the data secured, indicates a few points that appear to be reasonably consistent. Repulsion from the regular lime sulphur-arsenate is likely to be very temporary and appears to have little significance under field conditions. The addition of nicotine seems to increase the repulsion. Sulphur-lead arsenate has no appreciable repulsive action. In fact, some observations make it appear rather attractive than otherwise. Bordeaux, whether in dust or in liquid form, appeared to exert marked repellent action in most cases when bouquets were used; but this was not so evident under orchard conditions. Nicotine dust also seemed to drive the bees away and to remain repellent for some time after application. It may be noted that this dust is usually applied at a time of day when bees are inactive.

(f) FEEDING TESTS, 1932

In order to supplement the foregoing studies, various spray ingredients were fed directly to two-frame nuclei, the poison being incorporated in a sugar syrup (1-1), placed in honey can feeders and placed over the frames in the ordinary manner. Dead-bee traps were placed on all the hives. The following materials were used at the rate indicated:—

1. Calcium arsenate, 1 pound to 40 gallons.
2. Copper sulphate, 3 pounds to 40 gallons.
3. Sulphur dust, 25 pounds to 100 gallons.
4. Nicotine sulphate, 1 pint to 100 gallons.
5. Lime sulphur, 1 gallon to 40 gallons.

To summarize briefly the result of these tests, the bees refused to feed upon the syrup contained in Nos. 2, 4 and 5 to any appreciable extent and showed every evidence of repulsion. After the nicotine sulphate had been exposed on the frames for some time, there was a limited amount of feeding; but, as only a very few dead bees were found, it was evident that no extensive feeding took place. There was no sign of dead brood. Though few dead bees were found in the traps, a few larvæ were found in the combs two days later, showing that a slight amount of the poison must have been fed to the larvæ. The gas evolved from the lime sulphur solution made the bees restless at first, but caused little, if any, mortality for several hours. Little change occurred throughout the duration of the test; no further feeding was observed and only a few dead bees and larvæ were noted. The material was obviously strongly repellent. They fed upon the calcium arsenate, however, so rapidly and to such effect that within an hour almost the entire population was at the bottom of the hive in a dead or dying condition. There was no sign of repulsion and the bees fed upon the poisoned syrup at least as readily as upon plain syrup. So sudden and complete was the killing, that no additional evidence as to symptoms of arsenic poisoning was obtainable. There was no sign of recovery of any of the bees.

In the case of the sulphur dust, this was consumed quite readily by the bees; and, far from there being any evidence of repulsion, it seemed to be more attractive than the plain syrup. Droplets exposed on the tops of the frames were quickly lapped up, following which the bees attempted to consume the sulphur residue. There was, however, no pronounced mortality within five hours of the initiation of the test; but by 9 a.m. the next day many sick and dead bees were found in the trap, and "crawlers" were numerous in the grass. By 2 p.m. the bees that had been sick had gathered in bunches and were mostly dead. By 11 a.m. on the third day, sick, dying and dead bees were numerous in the trap, the living population had dwindled to a very few bees and some of the larvæ had apparently crawled out of the cells.

To sum up: copper sulphate, lime sulphur and nicotine sulphate, incorporated in sugar syrup in the dilution ordinarily used in spraying, and fed to bees, were so strongly repulsive that they were refused by the bees and, as a result, little poisoning resulted. Neither calcium arsenate nor sulphur dust gave any evidence of repulsion and were readily consumed. The former brought about the rapid extinction of the colony, but the latter was much slower in its action.

4. STUDIES FROM COMMERCIAL ORCHARDS

From time to time reports were received or cases were noted of apparent conditions of poisoning from commercial orchards. In such cases, samples of dead and sick bees, together with pollen and nectar, when procurable, were secured and subjected to chemical analysis. The results of these studies are set forth in the following pages.

(a) CHEMICAL DATA ON SAMPLES FROM COMMERCIAL ORCHARDS, 1928

A number of samples obtained from commercial orchards during the investigation furnish the data presented in the following table. Though complete analyses were made in most cases, only the most significant are included in the table. Furthermore, the results of many analyses, where relevant information is lacking, have been omitted entirely. Sufficient typical cases have been selected to give a fair picture of the situation throughout.

TABLE No. 34.—RESULTS OF EXAMINATION OF FIELD SAMPLES, 1920-1930

Orchard number	Date	Nature of samples	% (As) Arsenic	Ave. As. per bee (Internal) mg.	Remarks
1	31/5/28	100 bees	....	0·00023	Orchard sprayed with lime sulphur-calcium arsenate; poisoning evident.
	4/6/28	100 "	....	0·00023	
2	10/6/28	100 "	....	0·00043	While neighbour was dusting with sulphur-lead arsenate, bees began to arrive in front of hive in dying condition. Severe poisoning with death of brood followed.
3	20/6/28	3 lots of 100 bees	....	0·00029-0·00054	Very sudden and severe poisoning resulting, on examination of the two colonies, following application of 85-15 sulphur-lead arsenate to neighbouring orchard. Pollen from comb analysed ·00452 % arsenic; *sample of larvae ·00020 arsenic.* Apples not in bloom but wild radish in bloom in dusted orchard.
4	3/6/29	100 bees	....	0·00032	All 60 colonies showed severe poisoning of adults and brood, the two strongest most severe. All neighbouring orchards dusted with sulphur-lead arsenate and after each application large numbers of dead and dying bees appeared before hives.
5	3/6/29	74 "	....	0·00027	All 7 colonies suffered severely, two being completely exterminated following application of sulphur-lead arsenate to all neighbouring orchards. Much dead brood present and *pollen samples showed ·00237% arsenic; larvae sample,* ·00237% arsenic.
6	30/5/30	75 "	....	0·00006	Check sample of unpoisoned bees.
7	30/5/30	5 samples of 100 bees	....	0·00010-0·00028	Bees placed in orchard May 24, before bloom appeared; 7·5 and 8·6 hours sunlight on May 24 and 25 respectively; weather until June 1 cold and wet, temperature only once reaching 60°F. Five colonies exterminated by June 1, remaining 2 slowly died out. Poisoning took place before apple bloom. Typical of conditions in 1930 when severe poisoning occurred in nearly all apiaries before bloom.
8	10/6/32	100 bees	....	0·00045	Poisoning evident; no spraying done within 1½ miles of apiary.
9	*30/5/32*	*100* "	....	*0·00015*	*One colony badly poisoned; only spraying practised in neighbourhood of orchard.*
10	27/7/32	100 "	....	0·00033	This late poisoning was apparently due to a neighbouring orchard being dusted with poisoned Bordeaux dust for apple maggot. Wild radish in bloom in the orchard; mortality large.

(b) CONCLUSION FROM EXAMINATION OF COMMERCIAL SAMPLES OF DEAD BEES

The data obtained from analyses of samples of dead bees showed, in general, ponderable amounts of arsenic, from 2 to 14 times the quantity found in bees dying from natural causes. Poisoning occurred in all seasons, but was most pronounced following periods of dull, wet weather. Dead brood, taken from frames of the poisoned colonies also gave large percentages of arsenic. The results indicate that, in this orchard area, practically no period of the summer is entirely safe for hive bees.

(c) GENERAL SURVEY OF FIELD CONDITIONS

(i) *Fungicide Dusts.*—Orchards treated with poisoned copper fungicides have apparently served as the source of a certain amount of poisoning among bees, but the evidence on this point is neither so clean-cut nor so pronounced as in the case of sulphur-lead arsenate dust (90-10 or 85-15). In front of colonies poisoned by this latter mixture it was quite common to see carpets of bees 6-40 feet in length and of varying width. The bees so poisoned are unable to fly, but crawl or bunch on the ground in front of the hives. During 1929, the bloom came out very suddenly before many growers had applied their "pink" applications, resulting in much spray and dust being applied to bloom. We have records from nine lots of bees placed in locations widely separated from each other. In four of these areas no dusting whatever was done. No poisoning whatever occurred, so far as could be determined, in three of these apiaries. In the fourth, some poisoning did take place, but not of a type to be noticed by the casual observer. In another orchard where spraying had been practised, but not during

bloom, no poisoning was evident until an adjoining orchard was dusted with 90-10 sulphur-lead arsenate. Dusting was completed at 9 a.m. Examination at 4.30 p.m. revealed many " crawlers " and other unmistakable signs of poisoning, the colonies becoming seriously depleted as a result.

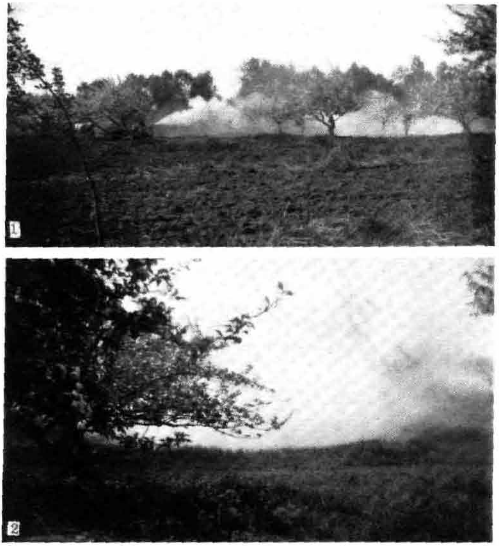


FIG. 70.—(1) Orchard dusting; (2) showing drift of dust cloud in orchard (original from photo by C. B. Gooderham).

Two groups of colonies were placed in the same district in 1929, but over a mile apart. All were in good condition up to May 30. Owing to rain and cold, no flight occurred in either apiary until June 5, when 90-10 sulphur-lead arsenate dust was applied to an orchard adjacent to one of these apiaries. Crawlers were present in front of all hives in this apiary and, for several feet in front of all colonies the ground was covered with dead bees, and there was a definite break in brood rearing. Dead bees and pollen showed a high content of arsenic. All other colonies placed in areas where sulphur-lead arsenate was applied suffered severely, many were killed outright and only with the greatest difficulty could the remainder be built up for overwintering.

(ii) *Sulphur Dust.*—Unpoisoned sulphur dust is frequently applied, especially in bloom, and is usually accompanied by dysentery among the bees. In 1929, no poison dusting was carried out about Gaspereaux, though considerable sulphur dusting occurred. Dysentery was quite pronounced, clothing hung out to dry being badly spotted. No positive evidence of serious mortality was obtained, and the colonies made continuous and satisfactory gains for severa

weeks, when slight poisoning occurred following further applications of poison dusts, wild radish (*Raphanus Raphanistrum* L.) being then in bloom. Feeding tests indicate that considerable mortality may be occasioned by unpoisoned sulphur dust, but not comparable to that caused by arsenicals.

(iii) *Nicotine.*—In all the orchards where apiaries have been placed, we have practised nicotine dusting during bloom, in order to eliminate injury from sucking insects such as the green apple bug (*Lygus communis Knight*) to the bloom. The applications were made at night or early morning when no bees were in the tree. A strong dust containing double the usual strength, *i.e.* 4 per cent of actual nicotine, was employed. Neither in these nor other orchards treated with commercial nicotine dust have we been able to detect signs of marked poisoning, though bees were noticed freely working the trees and occasionally became dusted with lime. It would appear that if deaths from the use of this preparation ever occur under field conditions, they must be too few to be detected by ordinary means. It has already been noted that nicotine dust is usually applied when the bees are not in the trees, and the rapid volatilization of the nicotine would remove the possibility of acute poisoning.

We have no field evidence of poisoning from nicotine sprays, and since this material is almost invariably used in combination with other materials, it would be difficult to isolate the action of this one ingredient. It is not, however, considered to be an important source of poisoning under field conditions.

(iv) *Arsenical Sprays.*—It is not possible to distinguish between the effects of different spray mixtures containing arsenicals, some growers using poisoned Bordeaux and some lime sulphur in almost every community, so that the exact source of the poisoning could not be determined in the majority of cases. As already noted, only one clear-cut case of poisoning from sprays occurred during 1929, but following that year such cases became increasingly frequent.

One of the best locations for making observations on bee poisoning from sprays was Long island, where no dusting had been practised for several years and where bees had been kept under close observation since 1928. Bees do not appear to fly across the two miles of dyke to the mainland in any number during bloom, though, of course, no one could say that such a flight never occurs. When the mainland orchards are blooming, the island orchards may still be bare, or nearly so, and, under such conditions, though flight might occur, we have failed to demonstrate it. When orchards on the island are in bloom and the mainland largely out of bloom we could never trace the bees to mainland orchards.

In 1928, some poisoning occurred, resulting in a loss of the field force which affected the performance of the hives very materially. Records of honey produced by 32 colonies left on the Island during the season of 1929 when similar conditions occurred, and 32 others kept outside during bloom and only taken to the island for the clover flow, are available. The two lots were as nearly similar as was practical to select them and all other conditions were equal. The production of the first lot was 2,200 pounds of honey, of the second 3,100 pounds. Analysis of bees from the first lot showed large amounts of arsenic in dead bees and excreta. We cannot prove that the bees did not secure this poison from dusted areas on the mainland, but it is noteworthy that colonies used from the same apiary in several other orchards, in which spray was employed, were not poisoned. Furthermore, a small apiary on the opposite mainland escaped noticeable poisoning. Moreover, results for the following three years on the same location, further support the belief that the poisoning was obtained on the island as a result of sprays. Poisoned Bordeaux was the spray used up to the time poisoning occurred. It should be said that there was little evidence of dead brood, there being no colonies killed outright and no definite break in brood rearing in these colonies during the years 1928-1931 inclusive.

The following two years similar poisoning took place. The season of 1930 was characterized by several days of cold weather in the pre-blossom period and during early bloom. May 26 to June 3, was generally cool with the thermometer not going above 62° F. at any time. The colonies were placed in certain orchards on May 24, in anticipation of immediate bloom, which, however, was so retarded by the cold weather that Gravenstein was not in full bloom until June 5. There was rain on May 27, 28, 29, 31 and on June 1 and 2. On June 3, the weather cleared and became warm and bright. During this period, May 30 was the only day when flight was possible, there being 7½ hours of sunlight, and considerable activity was noticed. Poisoning, in many cases severe, immediately developed. A number of colonies were wiped out, dead brood developed, and all colonies were so weakened that they were removed from the orchards as being useless for purposes of pollination.

In 1931, injury was particularly severe, which may at least, partially, be accounted for by the fact that heavier spraying was done with a higher arsenic content than ever before. Bees from a small apiary on the mainland worked the bloom in orchards immediately opposite, which were not sprayed as heavily as on the island. These bees showed no poisoning.

On June 2, 1932, about 100 colonies of bees were moved to Long island as Gravenstein was coming into bloom and careful investigation failed to yield any evidence that the bees were flying to the mainland in any numbers, and there is much evidence that they did not. June 3 was an ideal day for flight and the bees worked freely, but this was followed by five days of cold, damp and changeable weather during which their flight was inhibited, while on the 6th and 7th there was no activity whatever in the bloom. On the 8th there was a little activity and on the 9th fairly good conditions. Poisoning was evident on June 4 and increased each day thereafter. It was not of the sudden acute type so characteristic of poisoning from dust, though most evident after a rain. The bees at the east end of the Island suffered worst, more orchard and heavier spraying being done in that territory. The bees began to dwindle until June 23, when a careful examination showed that, in order to save the colonies, drastic uniting would have to be carried out and, accordingly, the original 105 colonies were united to make 68 new colonies, some of these consisting of little more than two or three frames covered with bees.

The foregoing case is important because we definitely know that the poisoning was caused by Bordeaux-arsenate spray, all growers on the Island confining themselves to this combination. The common formula used was 3-10-40 plus one pound of calcium arsenate, but many variations were used. In one case some Gravenstein bloom was out when the spraying was done, which was on the day previous to the colonies being introduced. It was noticeable that bees in this orchard suffered worst, though all colonies showed losses, even though no spraying had been done for five days previously. The accompanying tables are given to show the great reduction in strength as a result of this poisoning.

TABLE No. 35.—STRENGTH OF COLONIES MAY 11, 1932, BEFORE USING IN POLLINATION WORK*

Number of colony	Combs covered	Number of colony	Combs covered	Number of colony	Combs covered	Number of colony	Combs covered
238	5·0	267	7·0	206	5·5	87	7.5
151	6·0	120	9·5	A15	8·0	128	3·0
34A	5·0	264	4·5	154	9·0	132	4·0
220	5·0	250	8·0	39	4·0	228	3·0
214	6·5	273	6·5	95	9·0	117	10·0
89	6·0	232	6·0	282	4·5	348	10·0
121	5·0	279	4·0	237	9·0	210	5·5
78	9·0	284	5·5	231	5·0	131	5·0
209	8·0	257	6·0	B4	5·0	126	6·5
93	5·0	259	6·0	62	5·0	203	7·5
249	7·5	77	5·5	287	7·0	200	5·0
241	6·0	All	8·0	266	4·5	268	9·0
153	9·0	211	9·0	235	5·0	261	5·0
222	6·0	216	6·0	230	7·0	283	9·0
88	5·5	201	9·0	102	8·0	277	8·0
158	5·0	108	5·0	205	6·0	275	6·0
207	6·0	240	9·0	248	7·0	124	6·5
45	5·0	245	6·5	155	4·5	234	3·0
225	7·0	224	5·0	202	6·0	255	9·0
110	6·0	226	5·5	157	9·0	258	5·5
100	4·5	123	5·0	152	7·0	265	5·5
213	6·0	114	4·5	262	5·0	252	4·0
80	5·0	260	9·0	280	6·0	218	5·5
247	10·0	285	5·0	204	7·0	221	6·0
239	8·0	159	4·5	278	5·0		
233	9·5	227	7·0	272	8·0		
256	5·0	288	5·0	286	6·5		

*There was an increase in the strength of these colonies from 3 to 5 combs from May 11 to May 26. The latter date 50 colonies were moved to the Somerset orchard, where no poisoning occurred during the 6 days they remained. On June 2, all colonies were removed to Long Island and left there until June 10.

The following tables give the strength of the colonies on June 23, 1932, after having been used in the pollination work:—

TABLE No. 36

A. Colonies United Because of Weakness Due to Poisoning

Numbers of the colonies united			Number of combs covered in each colony united			Number of the colonies united			Number of combs covered in each colony united		
278,	207		1	1	1	234,	Dead				
264,	209		2	2		211,	88,	272	1	1	⅛
248,	241		2	1		158,	159,	262	1	½	¼
226,	B 4		2	1		218,	233		1½	1½	
258,	200,	93	2	1	1	108,	250		1¾	1½	
89,	220,	275	1½	1	1	231,	39		1½	1½	
240,	255		1½	1½		102,	77,	266	2	¼	2
205,	280,	34A	1½	1½	½	221,	132,	252	1½	1	1½
151,	230		1	½		A15,	225,		2	1	
204,	214,	153	2	1	1	202,	80		1½	1½	
286,	224,	228	2	½	½	100,	279,	123	2½	1	1
258,	128,	114	1½	1½	½	237,	235		2	1	
201,	265		⅓	¼	½	285,	131		2	1	
95, *	285		8	1		152, *	157		5½	1	
284, *	238		4	4							

* Queenless.

B. Colonies Left Ununited

Number of colony	Number of combs covered	Number of colony	Number of combs covered	Number of colony	Number of combs covered	Number of colony	Number of combs covered
121	2·0	261	8·0	78	3·0	45	3·0
34B	2·0	277	8·0	155	3·5	282	2·5
117	4·0	283	13·0	249	2·5	227	4·0
A11	6·0	110	5·0	213	4·0	222	5·0
206	5·0	210	8·0	87	4·0	126	3·5
239	4·0	259	7·5	247	4·0	245	8·0
120	4·0	282	5·0	124	8·0	203	9·0
256	8·0	277	5·0	154	8·0	273	8·0
260	5·0	62	4·0	287	7·0	131	2·0
288	5·0	216	11·0	257	7·0		

We have many records to show that orchards may be sprayed, even when considerable bloom is present, with the different commercial mixtures and no losses occur. Indeed, gains are frequently recorded in such cases; but, under certain weather conditions, as indicated in the next section, severe poisoning may take place. Complete loss of colonies seldom occurs and there is less loss of brood than is found in most cases of poisoning from sulphur-lead arsenate dust.

5. INFLUENCE OF WEATHER CONDITIONS ON BEE POISONING

One would expect that poisoning would be greatest in prolonged periods of weather favourable for flight and activity, and several workers have definitely stated that this is the case. It is, therefore, worthy of note that the most severe cases recorded were those which occurred following periods of cold, dull or wet weather, during which the bees were largely or entirely confined to the hives. With the coming of bright sunny weather "crawlers" would suddenly appear before the hives, and other symptoms of poisoning became evident. With the clearing of the weather the number of "crawlers" would gradually diminish. Though dwindling of brood might go on as a result of poison stores, no cases of new poisoning would develop until another period of dull weather when, with the return of flight, the condition would be repeated in more or less severity. Least poisoning was noted in the majority of cases during warm bright weather, even though poisons were applied to bloom.

In the Lakeville area where the conditions are definitely known, some interesting observations were made in 1929. All colonies were in good condition on May 30. Rain fell from 6 p.m. on that date, causing the growers to apply a dust, some the same night, others early next morning. This was very general all over the area, the dusts being sulphur-lead arsenate 90-10 and 85-15. May 31 to June 2 was cold and foggy, with mist and rain. On June 2, there were brief periods of sunlight throughout the day. The most severe symptoms of poisoning immediately became evident, and, when examined next day, some of the colonies were already practically exterminated.

In 1930, a number of colonies were set aside for poison tests during bloom, but heavy poisoning occurred before bloom, all colonies retained for the purpose being poisoned, and we had available for further poison tests only a few rented colonies which had been kept outside the sprayed area. Two were placed in an orchard which was heavily dusted with sulphur, one in an orchard dusted with sulphur-lead arsenate, and five in an orchard dusted with unpoisoned Bordeaux dust (12-88). The weather turned hot and bright and continued thus from June 3, when the hives were placed, until June 11 when they were removed. No poisoning occurred even in the orchard treated with sulphur and arsenate. This result is not necessarily conclusive, since a single colony in an area planted heavily to orchard may do most of its work elsewhere, but at least it is consistent with our other results.

Only two examples will be given from 1931. Bees were not placed in orchards until bloom was well started. On Long island bees were placed on May 29, the two preceding days being favourable for flight. No spraying had been done for six days previous to that date anywhere on the island. May 31 was bright and warm and great activity was noted at the hives. By 9 a.m. "crawlers" and clusters of sick bees were numerous. By noon most of the sick bees had disappeared and few were apparent the following day. The bees were removed to the South Mountain, out of the poison zone, and no further poisoning was noted. After several days of very rainy weather typical poisoning symptoms again became evident, even worse than before, and the colonies continued to dwindle for some time.

At Pereaux, 32 package colonies were placed in an orchard May 25 at 9 a.m. The day was cool and showery when the colonies were placed. Flight was limited, but, within an hour of placing, "crawlers" were observed near hives. At 5 p.m. as much as a cupful of dead bees was found in front of some hives. Spraying was general in the neighbourhood, but no dusting was done within a mile. No spray was actually on the apple blossom in the neighbouring orchards, but heavy spray was observable on grass, dandelions, etc. On the 26th it was foggy with frequent showers. On May 27 the day was clear and bright. There were no "crawlers" and apparently no further poisoning.

On Long island, poisoning was noticed in apiaries, particularly at the west and east apiaries, following rain on June 2, 1930. No spraying had been done for six days previous to this time, but most orchards had been sprayed quite heavily. Practically all orchardists used poisoned Bordeaux, but most of them used double the quantity of poison recommended. One man used lime sulphur-calcium arsenate-aluminium sulphate. Bees were noticed in early morning in considerable numbers lapping liquid from the leaves. In the afternoon when trees had dried, more were noticed at puddles. Bees were observed heavily working on trees covered with Bordeaux.

On June 8 and 9 the weather was cold and cloudy with some rain. Some bloom still remained on late varieties but most had fallen; spraying was general from June 5. Dead bees were noted on this date in large numbers in front of *all hives. Numbers of sick bees were noted crawling over the ground in the* orchard near the east apiary, which was newly sprayed with lime sulphur-iron sulphate mixture. The herbage was also covered with spray. Crawling bees were also found in a pasture northwest of the apiary where blueberry bloom was abundant. There was no dusting on the island within two miles of the apiary. It has already been fully described in the preceding section that periods of bee poisoning on Long island, in 1932, followed periods of dull wet weather.

Three factors may account for these results:—

1. Bees after confinement for several days appear thirsty and seek moisture on leaves and elsewhere with great activity, including that from leaves heavily coated with poison. Even during rains bees have been observed making short trips for water.

2. Pollen supplies being depleted during confinement, bees actively gather large quantities near the hives at the first opportunity.

3. During periods of weather favourable for flight poisoned pollen may be collected, but little actually consumed. During confinement they may feed on such poisoned stores, the sick or dead bees leaving or being ejected from the hives with the advent of favourable weather.

Nothing in this section should be interpreted as indicating that no serious poisoning ever occurs during periods of fine weather which is certainly not the case. The fact that the most severe cases of poisoning have occurred following periods of dull wet weather, seems, however, to be established.

6. SOURCES OF BEE POISONING (FOOD)

There are several possible sources from which poison may be obtained by bees; viz:—

(*a*) Pollen
(*b*) Nectar
(*c*) Water

(*a*) POLLEN AS A SOURCE OF BEE POISONING

Since pollen is eaten to a certain extent by adult bees, as well as fed to the brood, it would be expected to be a potent source of poisoning for both stages and actual observations and analyses show this to be the case. The following table shows analyses from tent experiments and field samples where definite poisoning occurred, and from two check samples.

TABLE No. 37.—ARSENIC, AS METALLIC As, FOUND IN POLLEN

No.	Year	Source	Weight	Arsenic (As)
			gms.	p.c.
1	1928	Lime sulphur—calcium arsenate	1·5666	·00116
2	1928	Lime sulphur—nicotine—calcium arsenate	1·0208	·00282
3	1928	Sulphur—lead arsenate	1·129	·00747
4	1928	Field sample (probably sulphur—lead arsenate)	2·9044	·00069
5	1928	Field sample (probably sulphur—lead arsenate)	0·8720	·00452
6	1929	Calcium arsenate	1·2960	·00111
7	1929	Bordeaux—calcium arsenate	1·3245	·00017
8	1929	Bordeaux—calcium arsenate—nicotine sulphate	1·7921	·00063
9	1929	Lime sulphur—calcium arsenate—nicotine sulphate	1·3870	·00060
10	1929	90–10	1·9820	·00057
11	1932	Field sample	0·9142	·00016
12	1932	Field sample	0·8150	·00019
13	1932	Field sample (check)	1·5390	nil.
14	1932	Field sample (check)	0·9038	nil.

It may be said that in all cases where severe poisoning occurred accompanied by dead brood, pollen analyses, when made, invariably showed ponderable amounts of arsenic. That the pollen secured is an important and, in many cases, the main cause of the poisoning would appear evident. It seems likely that the gradual dwindling away of a poisoned colony, after having been removed to a poison free locality, may be attributed largely to this cause. The sudden increase in deaths after a period of forced confinement may have a similar origin.

(*b*) NECTAR AS A SOURCE OF POISONING

At odd times throughout the course of this project samples of nectar have been collected and analysed. The percentages found are tabulated as follows:—

TABLE No. 38.—ARSENIC, AS METALLIC As, FOUND IN ANALYSES OF SAMPLES OF NECTAR

No.	Year	Source	Method of securing sample	Arsenic (As)
				p.c.
1	1928	Field sample	Shaken from frames	·00001
2	1929	Field sample	Shaken from frames	·00003
3	1931	Apiary Hive No. 104	Pipetted from cells in frame	nil
		"	Shaken from frame	·00005
4	1931	Bee Division, Ottawa	Pipetted from cells	·00006

The small amount of poison found, even when samples were secured in such a way as not to preclude the possibility of contamination, would indicate that nectar is not an important source of brood poisoning which is evidently derived mainly from other sources. Nevertheless, since young larvae may be very susceptible, this possibility cannot be entirely eliminated without further information.

(c) WATER AS A SOURCE OF POISONING

Bees are frequently observed consuming water that drips from limbs or collects in drops upon leaves covered with spray. This is particularly noticeable after they have been confined several days by dull rainy weather.

In this connection a few typical quotations from the literature as to the use that bees make of water may be of value. Root and Root (1929, pp. 745-746) state " The gathering of water is more noticeable in the period of early spring brood rearing and in hot weather than at other times." Langstroth and Dadant (1927, pp. 101-103) state " water is necessary to bees to dissolve the honey, which sometimes granulates in the cells, to digest pollen and to prepare the food with which they feed the larvae."

" Bees take advantage of any warm winter day to bring it to their hives, and in the early spring may be seen busily drinking around pumps, drains, and other moist places. Later in the season they sip the dew from grass and leaves."

" That bees cannot raise much brood without water, unless they have fresh-gathered honey, has been known from the times of Aristotle. Buera, of Athens (Cotton, p. 104) said in 1797, ' Bees daily supply the worms with water; should the state of the weather be such as to prevent the bees from fetching water for a few days, the worms would perish. These dead bees are removed out of the hives by the worker bees if they are healthy and strong; otherwise, the stock perishes from their putrid exhalations'."

Phillips (1928, pp. 95, 135-136) notes " Water is needed at practically all times during the breeding season, perhaps more especially in hot weather. The bringing of water to the hive is most noticeable in the early spring."

" The collection of water by field bees is most commonly observed in early spring and during the hottest parts of the summer, there probably being less need for water when the humidity within the hive is high because of the evaporation of nectar. Bees have been known to collect water in quantity in extremely hot weather and to place it on the bars within the hive, from which places it disappears by evaporation, thus reducing the temperature within the hive."

Langstroth (1914, pp. 293-294) states regarding the necessity of water for bees as follows: "It is absolutely indispensable when they are building comb or raising brood. But as soon as the grass starts and the trees are covered with leaves they prefer to sip the dew from them. As soon as the weather becomes warm, and the bees can supply themselves from the dew on grass and leaves it will not be worth while to give them water in their hives."

Cowan (1890, p. 7) remarks: " Water is also used, but it is not stored, and the bees only collect it as required."

Our own observations indicate that considerable water is consumed during apple bloom. Bees have been noted sipping it from pools in the orchard after a rain, from spray covered herbage beneath the trees and from the foliage and petals of the apple trees. Even in very dark weather and during light rains, small numbers of water-collectors make their short flights from and to the hive. In one case they were seen, under such conditions, freely sipping water from a spruce hedge adjacent to the apiary. The foregoing may at least in part explain why such marked poisoning occurs after each rain. Drip water from different situations from which bees were observed to consume it was collected and analyses performed. The results are presented in the accompanying table. The

samples of water were pipetted from apple petals, leaves and from blades of grass growing beneath the trees. The liquid samples were filtered before analysis, so that the data indicate soluble arsenic or copper, or the colloidal state of these metals.

TABLE No. 39.—ARSENIC, AS METALLIC As, IN MG. FOUND IN RAIN WATER FROM LEAVES, ETC., IN SPRAYED AND DUSTED ORCHARD

No. of sample	As. in mg. per litre	Copper as metallic cop. in mg. per litre	Treatment of orchard
1	*nil*	*nil*	Check.
2	0·7575	Not taken	Sprayed with lime sulphur—calcium arsenate—aluminium sulphate mixture. Petals and leaves.
3	1·0810	"	Same as foregoing.
4	1·7201	"	Bordeaux, 8–35–100 used, plus 6 lbs. calcium arsenate. Heavy rain all morning before taking sample.
5	8·5720	"	Lime sulphur—calcium arsenate—iron sulphate mixture used. Light rain in morning before taking samples.
6	15·3750	"	Same as above, but in different part of orchard.
7	18·9002	"	Dusted previous day with sulphur—lead arsenate (90–10). Heavy rain fell following application.
8	1·8040	"	From blades of grass in same orchard as preceding.
9	None taken	0·027	Sprayed with Bordeaux, 6–18–160 on June 3 and 4. Sample taken June 6 following heavy downpour.

7. SOURCES OF BEE POISONING (PLANTS)

It has sometimes been assumed that the apple or other fruit bloom is the sole source of poisoning, but the role of other flowering plants growing in or near the orchard should be emphasized. Poisoning is generally first noticed with the dandelion bloom, and the later cases of serious poison are usually associated with the blossoms of the wild radish (*Raphanus Raphanistrum* L.). Both of these plants are very common about all the orchards and both of them are heavily worked by bees.

During the course of these investigations every effort has been made to determine the source of cases of poisoning occurring after and before bloom, and in most cases we were forced to the conclusion that the former was the source of the pre-blossom poisoning, while the latter accounted for most post-blossom cases. In a few cases local orchard weeds, as ground ivy (*Nepeta hederacea* (L.) Trevisan) or adjacent clover fields, may be responsible; but the former two are evidently the only two species of plants widely involved in cases of poisoning. The foregoing does not include those cases of poisoning that may be due to poisoned water obtained from spray or dust covered grass or herbage growing beneath treated trees.

Some chemical data relating to this subject were secured in 1931 and 1932. Samples were taken from dandelion, strawberry blossoms, rhododendron and ground ivy in sprayed, dusted and untreated orchards. In addition, whole flower heads of dandelion were removed (with a razor) just above the receptacle. In other cases, apple stamens just below the anthers were similarly removed. In the case of the strawberry blossom, the whole flower without the sepals was taken for analysis. Whole flowers from rhododendron and ground ivy were employed in the tests.

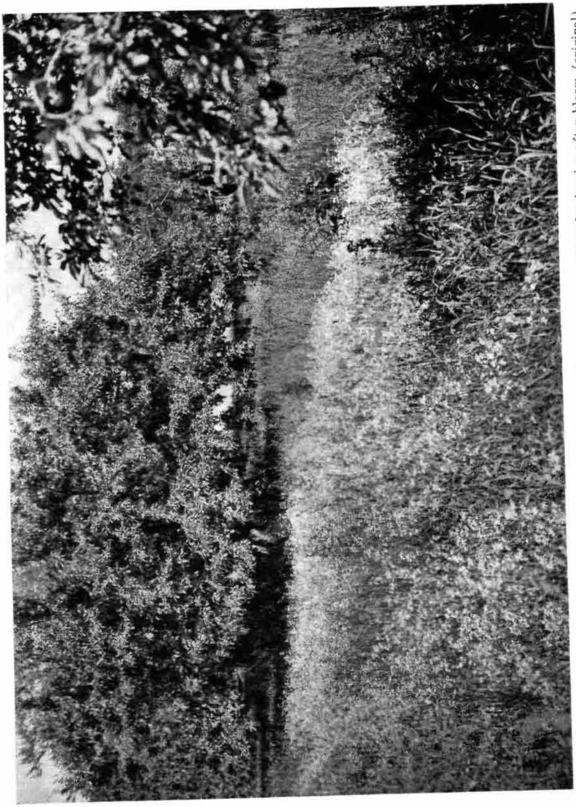


FIG. 71.—Wild radish (*Raphanus Raphanistrum* L.) in orchard. A common source of poisoning after bloom (original).

TABLE No. 40—ARSENIC, AS METALLIC As, FROM DANDELION AND STRAWBERRY BLOOM AND STAMENS FROM DUSTED AND SPRAYED ORCHARDS

No.	Date of collection	Source of material	Material used	No. in sample	Arsenic, as metallic As.		Remarks
					milligrams	p.c.	
1	28/31	Check	Dandelion heads	12	·0002	....	Taken from untreated area.
2	*27/31*	*Dusted orchard*	*Dandelion heads*	*12*	*·0394*	....	*Collected while orchard was* being dusted with sulphur-lead arsenate (90-10).
3	*27/31*	*Sprayed orchard*	*Dandelion heads*	*12*	*·1430*	....	*Sprayed with "Wet-tex",* previous day, guaranteed to contain sulphur, not less than 56%; lead arsenate, not less than 18%; other ingredients, not over 26%. No rain fell between application and cutting of samples.
4	28/31	Check	Strawberry bloom	12	nil	....	
5	27/31	Dusted orchard	Strawberry bloom	12	·0061	....	Same data as No. 2.
6	27/31	Sprayed orchard	Strawberry bloom	(No bloom present)			
7	28/31	Check	Apple stamens	30	....	nil	
8	27/31	Dusted orchard (1)	Apple stamens	30	....	·0044	
8a	28/31	Dusted orchard (2)	Apple stamens	30	....	·0006	Same data as No. 2.
9	27/31	Sprayed orchard (1)	Apple stamens	30	....	·0069	Same data as No 3.
9a	28/31	Sprayed orchard (2)	Apple stamens	30	....	·0011	Same data as No. 3.
10	3/6/32	Check	Dandelion heads	12	0·0007	....	All check material collected from unsprayed areas, or undusted areas.
11	*31/5/32*	*Sprayed*	*Dandelion heads*	12	1·40	....	Bordeaux 8–35–160 plus 6 lbs. calcium arsenate used on *May 30.*
12	3/6/32	Sprayed	Dandelion heads	12	0·0078	....	Bordeaux 4½-25–120 plus 5 lbs. calcium arsenate used on May 30 and 31.
13	3/6/32	Dusted	Dandelion heads	12	0·0230	....	85-15 sulphur-lead arsenate used at rate of 60 lbs. per acre on June 2.
14	2/6/32	Check	Strawberry blossoms	12	nil	....	
14a	2/6/32	Check	Strawberry blossoms	12	nil	....	
15	*3/6/32*	*Dusted*	*Strawberry blossoms*	*12*	*0·0068*	....	*Same data as No. 13.*
16	2/6/32	Check	Rhododendron bloom	12	nil	....	
16a	2/6/32	Sprayed	Ground ivy	25	0·0228	....	Wettable sulphur containing 6 lbs. of calcium arsenate to 160 gallon tank.
17	2/6/32	Check	Apple stamens	25	....	nil	
17a	3/6/32	Check	Apple stamens	25	....	nil	
18	2/6/32	Sprayed	Apple stamens	25	....	·2150	Lime-sulphur-aluminium sulphate mixture plus 2 lbs. calcium arsenate per 100 gals.
19	*2/6/32*	Dusted	*Apple stamens*	25	....	*·0041*	*85-15 sulphur-lead arsenate* applied previous day followed by heavy rain.
20	3/6/32	Dusted	Apple stamens	25	....	·0017	Same data as No. 13.
21	3/6/32	Dusted	Apple stamens	25	....	·0021	Same data as No. 13.
22	9/6/32	Dusted	Apple stamens	25	....	·0016	Dusted previous day with sulphur-lead arsenate (90-10). Heavy rain followed application.

The fact that samples from both dusted and sprayed orchards show arsenic present, in quantity likely to cause trouble if gathered by bees, is apparent. The total arsenic taken from whole dandelion heads was generally greater in the sprayed than in the dusted orchard, sometimes very much greater. The stamens, on the other hand, especially the first collection in 1931, sometimes show more arsenic from the dusted trees. The analysis of the second collection shows a decidedly smaller quantity of arsenic than the first—this may be due to the wind shaking off the sulphur dust, or the uneven dusting. Rain falling after application evidently removes dust more readily than spray.

The difference in the character of the spray deposit is evidently more important than the actual amount present. The dust is loosely exposed and readily gathered by the body hairs and stored in the pollen. The spray forms a film less readily dislodged and less likely, after drying, to be removed by bees, except as it becomes dissolved in rain or dew, when it may be imbibed, or the film may be softened and lapped up by the bees. This would help to explain why we do get serious injury from spray following a rain.

FIG. 72.—Yellow rocket (*Barbarea vulgaris* R. Br.). Such weed is occasional source of poisoning during bloom (original).

8. INFLUENCE OF COLONY SIZE AND APIARY SIZE ON BEE POISONING

Large colonies, because of their greater field force, suffer worse, proportionately, than weak colonies or package bees, as a general rule. Similarly, in large apiaries our observations indicate, on the whole, greater losses. This may be because the bees from small apiaries are not obliged to work the whole area intensively.

9. INFLUENCE OF TIME OF PLACING IN THE ORCHARD

The period for bee poisoning extends from some time before the apple comes into bloom until some time thereafter, and where poison sprays for apple maggot are applied it may extend into August. It is frequently more severe shortly before and shortly after the bloom than during that period, partly because more spraying or dusting is done at that time and partly because less bloom is then present and the bees concentrate on bloom growing in and near the orchards. In most districts, little poison is applied during the period of full bloom. Some of the early bloom usually gets sprayed, as well as some of the late bloom. Spraying or dusting during bloom, when practised, is usually though unfortunately not always, with a fungicide only. Only a small proportion of growers use poison in the dust during bloom. At this period bloom is abundant and the bees range widely. Poisoning may occur during bloom as a result of pre-blossom sprays, especially under certain weather conditions, as already explained.

The foregoing will clearly indicate that when bees are to be placed in the orchard for pollinizing purposes, it is advisable, from all standpoints, to do so only after the early varieties are in bloom, and to remove them before the calyx application is made. Even this may not avoid injury under all conditions, but it will, at least, reduce it to a minimum.

10. EVIDENCE OF POISONING AMONG WILD BEES

From the very nature of things, field evidence of poisoning among wild bees is very hard to obtain. Curiously enough, they may be found nesting in great numbers in areas where the most severe losses of hive bees have taken place.

Dead brood could rarely be found in the nests, and dead bees never occurred in large enough numbers in nests to indicate poisoning, though large numbers may succumb as a result of drowning within the nest. It may be that such bees never reach the nest, but die in the orchard and so cannot be detected.

The result of analysis of pollen from districts where dusting is generally practised is therefore of interest.

TABLE No. 41—ARSENIC (As) FOUND IN POLLEN, FROM NESTS OF WILD BEES

Source	Date	Weight	Arsenic (As)	Species
		gms.	p.c.	
No. 1—Lakeville	20-6-29	....	0·0031	*H. smilacinæ*
No. 3—Woodville	22-6-29	....	0·0005	"
No. 4—Lakeville	22-6-29	....	0·0019	"
No. 6—Woodville	23-6-29	....	0·0017	"
No. 1—Long island	5-7-30	0·1270	0·0018	"
No. 2—Long island	9-7-30	1·0900	0·0002	*H. craterus*
No. 3—Long island	10-7-30	1·3830	0·0003	*H. smilacinæ.*
No. 6—Centreville	15-7-30	0·7780	0·0003	*H. arcuatus*
No. 7—Lakeville	19-7-30	0·0890	0·0026	*H. smilacinæ*
No. 8—Centreville	18-7-30	2·4454	0·0002	*H. arcuatus*
No. 9—Centreville	18-7-30	0·0980	nil	*H. craterus*
No. 10—Centreville	18-7-30	0·1234	nil	*H. smilacinæ*
No. 11—Centreville	18-7-30	0·4030	0·0006	*Andrena formia*
No. 12—Blomidon (Shore)	21-7-30	0·0747	nil	*H. smilacinæ*
No. 13—Welsford	24-7-30	0·9720	0·0002	*H. smilacinæ*

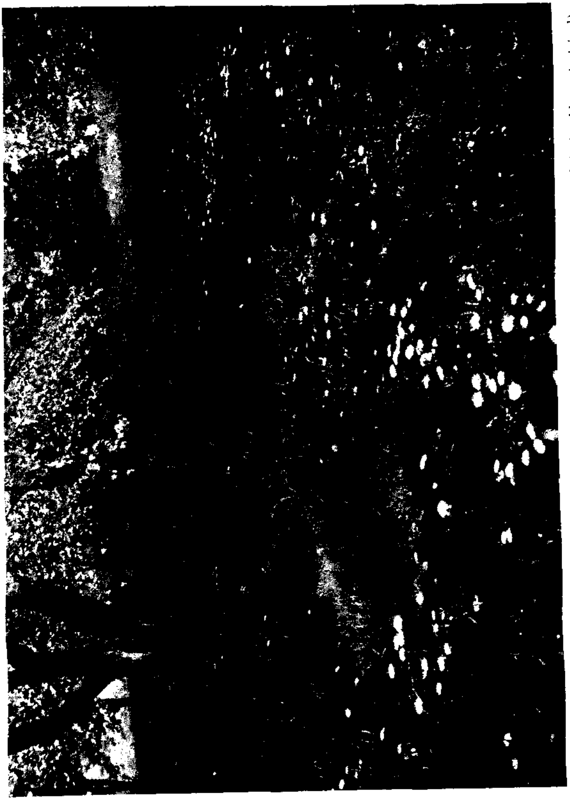


FIG. 73.—Dandelion (*Taraxacum officinale* Weber), a common source of poisoning before and during bloom (original).

The fact that such a large proportion of the pellets, collected at random, contain measurable amounts of arsenic would lead one to suppose that poisoning among wild bees should be common; but if so, it is difficult to demonstrate, and over the period studied we have not been able to detect any diminution in the effective population traceable with certainty to this cause. Much more careful studies over a longer period would be necessary before we could speak with confidence on this point.

11. SUMMARY OF POISON TESTS

(*a*) The question of poisoning of bees from poison sprays and dusts used in orchards is obviously important from the standpoint of their utilization for pollination purposes. A survey of the situation shows that the hive bee population has been greatly depleted during recent years and the evidence points clearly to the conclusion that this has been directly due to the use of poison sprays and dusts. With the advent of dusting, many apiaries were completely wiped out, so that no large commercial apiaries, except those that were removed during the danger period, remained. The growing practice of using larger spray outfits, resulting in heavier applications, and a different type of spray nozzle resulting in greater drift to surrounding vegetation, has increased the incidence of poisoning from this cause.

(*b*) The most important fungicides used are (1) lime sulphur in various combinations using calcium or lead arsenate as a poisoning ingredient; (2) copper sulphate in the form of Bordeaux mixture or copper-lime dust, to which one of the foregoing poisons has been added; (3) sulphur dust usually in combination with lead arsenate, and (4) nicotine sulphate in liquid form or in the form of a "contact dust," with hydrated lime as a filler. Under orchard conditions it would appear that arsenic in the form of lead or calcium arsenate is the main source of bee poisoning in these mixtures; but even sulphur dust alone may cause trouble, though not comparable to that caused by arsenicals. Clear evidence of repulsion from copper sulphate, lime sulphur and nicotine is obtained from tests under controlled conditions; but under orchard conditions this repulsion appears to be temporary and does not prevent serious losses from occurring.

(*c*) Arsenical poisoning results in partial to complete paralysis and is first evidenced by "crawlers" appearing in front of the hive; bees come together in bunches; the abdomen is distended and severe dysentery makes its appearance, followed by death of adult bees. This is soon followed by death of larvae and pupae. Symptoms of sulphur poisoning are similar but less severe. Clear cases of copper or nicotine poisoning under field conditions were not obtained.

(*d*) When the internal arsenic in bees is greater than ·00004 mg. of metallic arsenic per bee, poisoning may be expected, definitely so, when higher than ·0008 mg. is detected.

(*e*) Field observations, supplemented by chemical analyses of numerous samples, lead to the following conclusions:—

(i) All sprays containing an arsenical as an ingredient were dangerous when applied during bloom.

(ii) Only sprays or dusts containing arsenicals resulted in dead brood.

(iii) The combination causing the most sudden and complete mortality was sulphur-lead arsenate in dust form.

(iv) In general, less mortality resulted from sprays and dusts containing copper or nicotine as an ingredient along with the arsenical.

(v) Sulphur dust free from poison may cause death of bees, but to what extent this occurs under field conditions is not clear. Evidently it is much less deadly than arsenicals, besides being less sudden and complete in its action.

(vi) Field observations, supplemented by chemical analyses indicated that the greatest poisoning usually occurs just previous to and just after the main bloom. Nevertheless, no time during the season from May until August is completely safe. Sprays for apple maggot applied as late as August sometimes cause severe poisoning.

(*f*) Weather conditions have an important bearing on the incidence of poisoning among bees. Very severe poisoning has been noted even when prevailing conditions are cool and wet, and some of the worst cases have taken place following brief bursts of fine weather intervening between periods of broken weather. On the other hand, attempts to secure poisoning by placing a few hives in an orchard, sprayed or dusted with the most deadly mixtures when the weather was optimum for flight, have sometimes resulted in failure. Several factors may account for this:—

(i) Bees after several days confinement greedily seek moisture from poisoned leaves, petals and poison-covered herbage growing beneath trees, which analyses show to contain large quantities of arsenic.

(ii) During confinement, supplies are depleted and at the first opportunity bees are very active in collecting new stores near at hand, resulting in much poisoned pollen being brought in.

(iii) During periods of weather favourable for flight, poisoned pollen may be collected but not consumed, and this may be fed upon during periods of confinement.

(*g*) *The main source of poisoning of bees and brood is evidently pollen,* but, under certain conditions, drop water from sprayed leaves, petals or herbage *growing in the orchard may be a very important factor.* Some writers mention nectar, but our analyses show either no poison in the nectar or only minute amounts, and the possibility that this may be due to contamination in gathering the sample is not entirely excluded in some cases. Nevertheless, even the minute quantities detected may be deadly to very young larvae.

(*h*) It is often assumed that poison applied to the fruit bloom is the chief or sole cause of loss, but this is not the case. Severe cases of poisoning before and during bloom are sometimes attributable to poison obtained from dandelion bloom growing in or near the orchard. Later cases of poisoning were mainly traceable to wild radish; but many other plants may serve as sources of poisoning due to the drip or drift of poisoned sprays or dusts.

(*i*) It was noticed that large colonies and large apiaries often exhibited the most severe poisoning.

(*j*) Least trouble was experienced when bees were not placed in the orchards until the early varieties were in bloom after the application of the "pink" spray and taken away before the beginning of the "calyx" spray. For reasons already given, however, this did not eliminate all cases of poisoning, though it reduced them to a minimum. It is impossible, however, to maintain apiaries anywhere in the entire fruit belt at any time from May until August, without incurring some risk of loss.

(*k*) Samples of pollen taken from the nests of solitary bees showed ponderable amounts of arsenic, more than enough to destroy the larvae of hive bees. Evidence of depletion of the solitary bee population from this cause is difficult to secure and requires further observation.

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